AD-A008 186

EVALUATION OF ELECTROSTATIC PROBE TECHNIQUE FOR DETECTION OF PARTICLES EMITTED DURING TURBINE ENGINE DISTRESS

Donald A. Mitchell, et al

Air Force Aero Propulsion Laboratory
Wright-Patterson Air Force Base, Ohio

November 1974

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AIR FORCE/56780/15 April 1975 — 100

UNCLASSIFIED
Security Classification

AD-A008 186

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Air Force Aero Propulsion Laboratory (TBP)
Wright-Patterson AFB, Ohio 45433

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

EVALUATION OF ELECTROSTATIC PROBE TECHNIQUE FOR DETECTION OF PARTICLES EMITTED DURING TURBINE ENGINE DISTRESS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final - 15 Jan 74 - 15 Mar 74

5. AUTHOR(S) (First name, middle initial, last name)

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6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1974	86	11

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. 3066

c. Task No. 306613

d. Work Unit No. 30661309

9a. ORIGINATOR'S REPORT NUMBER(S)

AFAPL-TR-74-41

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Air Force Aero Propulsion Laboratory
Turbine Engine Division
Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

Electrostatic probes were inserted into the turbine exhaust of a J57 gas turbine engine in an effort to detect particles generated by artifically induced distresses of certain gas path components, thereby serving as an indication of incipient component failure. The two types of distresses induced were simulations of turbine rub and combustor burn, each of which is often accompanied by particle release into the gas flow. Results of this evaluation indicate that probe output signals due to particle impact with the probe could not be reliably detected above the baseline noise level for the distresses simulation in this effort. (U)

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electrostatic Probe						
Turbine Engines						
Particle Emission						
Particle Detection						
Failure Prediction						
Engine Failures						

UNCLASSIFIED
Security Classification

☆U.S.Government Printing Office: 1975 — 657-020/496

AFAPL-TR-74-41

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FOREWORD

This final report was prepared in the Air Force Aero Propulsion Laboratory (AFAPL), Turbine Engine Division, Propulsion Branch (TBP), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The work reported herein was accomplished under Project 3066, "Turbine Engine Propulsion". Task 306613 "Diagnostics and Instrumentation". It was co-authored with the Air Force Flight Dynamics Laboratory (AFFDL) under Project 1987, Task 02. The authors are 1st Lt. Donald A. Mitchell (AFAPL/TBP) and 2nd Lt. Mario Soliz (AFFDL/FGL).

This report covers only one test effort that has been conducted in an evaluation of the electrostatic probe technique. Several other efforts, including contractual and joint investigations, have also been conducted. Reports are presently being prepared on these projects and results are expected to be available in mid CY74. A comparative analysis of results from all programs will then be carried out and published by the AFAPL and AFFDL project engineers.

The authors would like to thank Mr. David Elkins and Mr. Paul Habil of AFAPL for engine maintenance and operation. Much valuable engineering and technical support was provided by Mr. Nick Stucke and Mr. Carl E. Wetherholt of Technology Scientific Services, Inc., of Dayton, Ohio.

This report covers the test period 15 January 1974 to 15 March 1974.

This report was submitted by the authors on 1 May 1974.

This technical report has been reviewed and is approved.

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ABSTRACT

Electrostatic probes were inserted into the turbine exhaust of a J57 gas turbine engine in an effort to detect particles generated by artifically induced distresses of certain gas path components, thereby serving as an indication of incipient component failure. The two types of distresses induced were simulations of turbine rub and combustor burn, each of which is often accompanied by particle release into the gas flow. Results of this evaluation indicate that probe output signals due to particle impact with the probe could not be reliably detected above the baseline noise level for the distresses simulated in this effort.

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ILLUSTRATIONS (CONTD)

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SECTION I
INTRODUCTION

Approximately two years ago, an electrostatic probe technique was put forth as a method for predicting imminent failure of turbine engine gas path components (Reference 1). This method proposes use of the probe as an electrode which detects metal particles in the engine exhaust due to spalling, flaking, burning, etc. of the distressed components. Since formulation of this idea, a number of tests have been conducted in an attempt to evaluate the potential for practical application. Evaluation has included more fundamentally oriented studies such as combustor (References 2, 3, and 4) and plasma torch testing (Reference 5), as well as testing on full scale turbine engines (References 5, 6, 7, and 8). Theoretical studies (References 9 and 10) have also been atttempted but have had limited success in defining fundamentals leading to particle detection by the probe.

In the past, the J57 engine has been a favorable test article in support of the case for satisfactory probe utilization, partially due to the fact that this technique was originally discovered and developed on this engine. Distress testing as carried out in the present effort was believed to be very critical for demonstrating the capability of the probe concept. As similar testing was initiated earlier in an evaluation by the Federal Aviation Administration (FAA) (using J60 turbojet engines) with results far from favorable, it was deemed appropriate to repeat the distress evaluation on a J57 where our past experience had been more encouraging.

The objectives of this effort were: (1) simulate the two types of gas paths related distresses most likely to cause particle emission prior to engine failure; (2) assess the capability of the electrostatic probe technique for particle detection; (3) document signal waveforms for analysis of information content and to insure that the signals were not due to coincidental extraneous interference.

The distresses chosen for simulation in the tests reported here are those indicated as most favorable for satisfactory probe detection. This assessment was based on instances of engine failures (or limited distresses) encountered in probe testing by engine manufacturers under contract to the Air Force (References 4, 6, and 7), as well as tear-down reports on engine failures (Reference 11) filed by the Air Force engine overhaul shops.

SECTION II
TEST EQUIPMENT AND PROCEDURE

The general test configuration is shown in Figure 1. The J57 turbojet engine was mounted on a static, ambient pressure, thrust stand with standard test cell instrumentation and manual throttle controls. Particle generation and release into the gas flow was produced by introduction of distress conditions at the locations indicated in Figure 2 and are described in the following paragraphs. Electrostatic probes for particle detection were located behind the turbine stages, as shown later in more detail in Figure 11. Probe signals were transmitted by shielded transmission line to pulse detection circuits located in the engine control room. More detailed descriptions of the test hardware are given below.

The J57 is a two-spool turbojet employing a nine stage axial flow low pressure compressor and a seven stage high pressure compressor. The combustor section consists of eight thru-flow can-annular combustors with a discharge temperature of about 1570°F. A single axial turbine stage drives the high pressure (HP) compressor and two stages drive the low pressure (LP) compressor. Normal rated thrust for standard day sea level conditions is about 9000 lbs. The J57-37 model employed in this testing is non-afterburning and differs from other models of the J57 in regard to certain accessories such as those associated with water injection takeoff, for which the -37 is not equipped. Internally the engine structure is the same as other models except for the incorporation of titanium in the LP compressor section of the J57-19W and -43W.

A sectional diagram of the engine is presented in Figure 2. The numbers below the diagram indicate engine station designations. Above the diagram are numbers to indicate the test designation for each case of distress simulation. Each test number has a numbered arrow showing the location of the distress point.

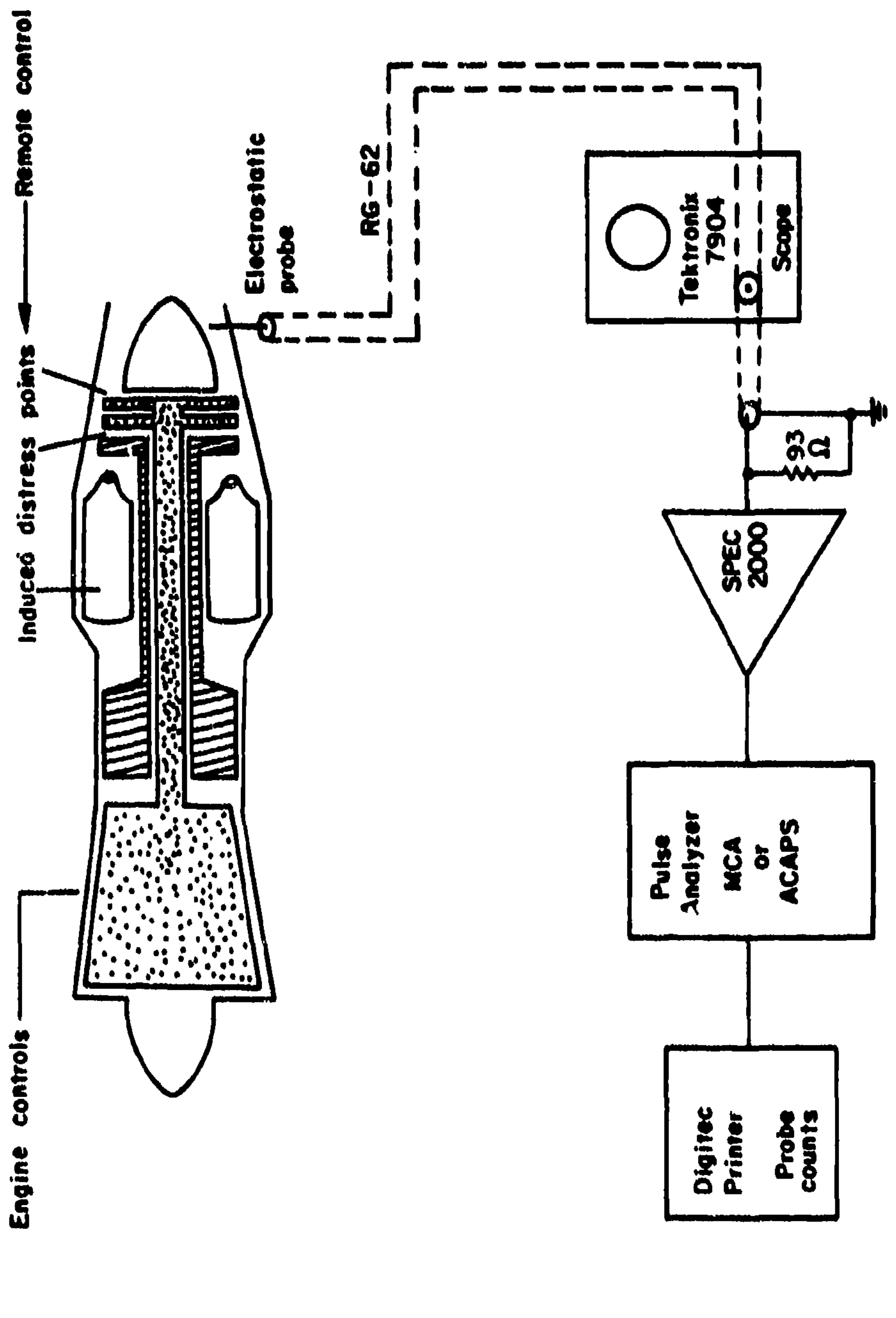


Figure 1. General Test Configuration

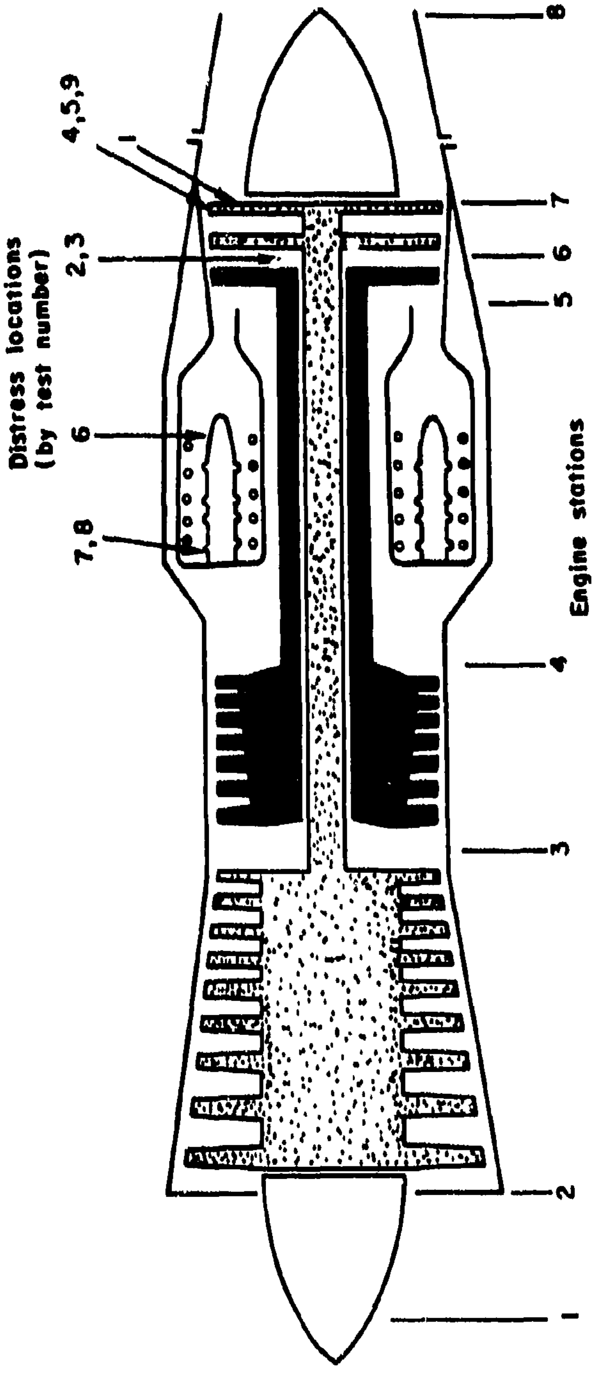


Figure 2. Engine Stations and Distress Locations

Production of each distress was achieved by inserting a 5/16" diameter metal rod into the engine at the proper distress location. The rod insertion was controlled remotely by a motor-driven lever. This mechanism is shown in Figure 3.

Stage 2 LP turbine rub was achieved by inserting the rod through a spare pressure/temperature port in the exhaust case as shown in Figure 4. The distress location giving the best results as far as particle generation and convenience was at a position on the trailing edges of the stage 2 LP turbine blades about 2" from the shroud. This area is shown in Figure 5, which is a photograph of the trailing edge side of this stage after all testing had been completed. Some wear on the blades due to the rub can be observed in this photograph. Due to the greater hardness of the blade material, most particle generation was due to material loss from the rub rod. Figure 32, presented later, shows the typical appearance of the rub rod tip after a successful rub test. The flaired appearance of the tip was produced by the frictional heating and pounding effect of the rotating blades. Typically, 0.5 to 3.5 grams of rod material was worn away during testing. Particle generation was verified by observation of the area behind the exhaust through a porthole in the test cell wall. During the successful rub attempts, glowing streaks of particles could be observed exiting the engine over a region large enough to ensure particle impact with one or more probes. Although a few particles did stick to the probes, most particles would not be expected to plate out on the probe surfaces since the gas temperature was well below the material melting point and the particles would loose some heat to the exhaust gas.

Attempts to produce rub on the trailing edges of the HP turbine rotor blades (Tests #2 and 3) were not totally successful due to an insertion hole alignment problem. This problem was due to a shift in the desired distress location relative to the insertion hole in the engine case when the engine was operated at thrust levels significantly above idle. The rub rod in these instances missed the blade edges and passed into the area at the base of the blades where cooling air

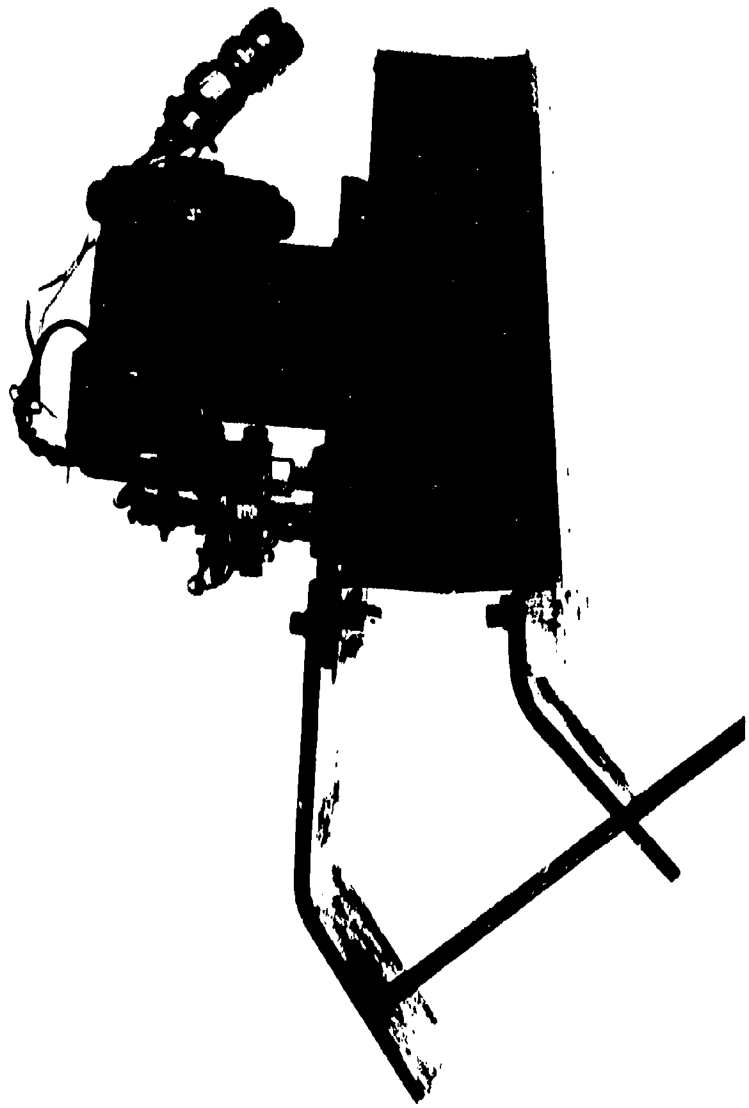


Figure 3. Rod Drive Mechanism

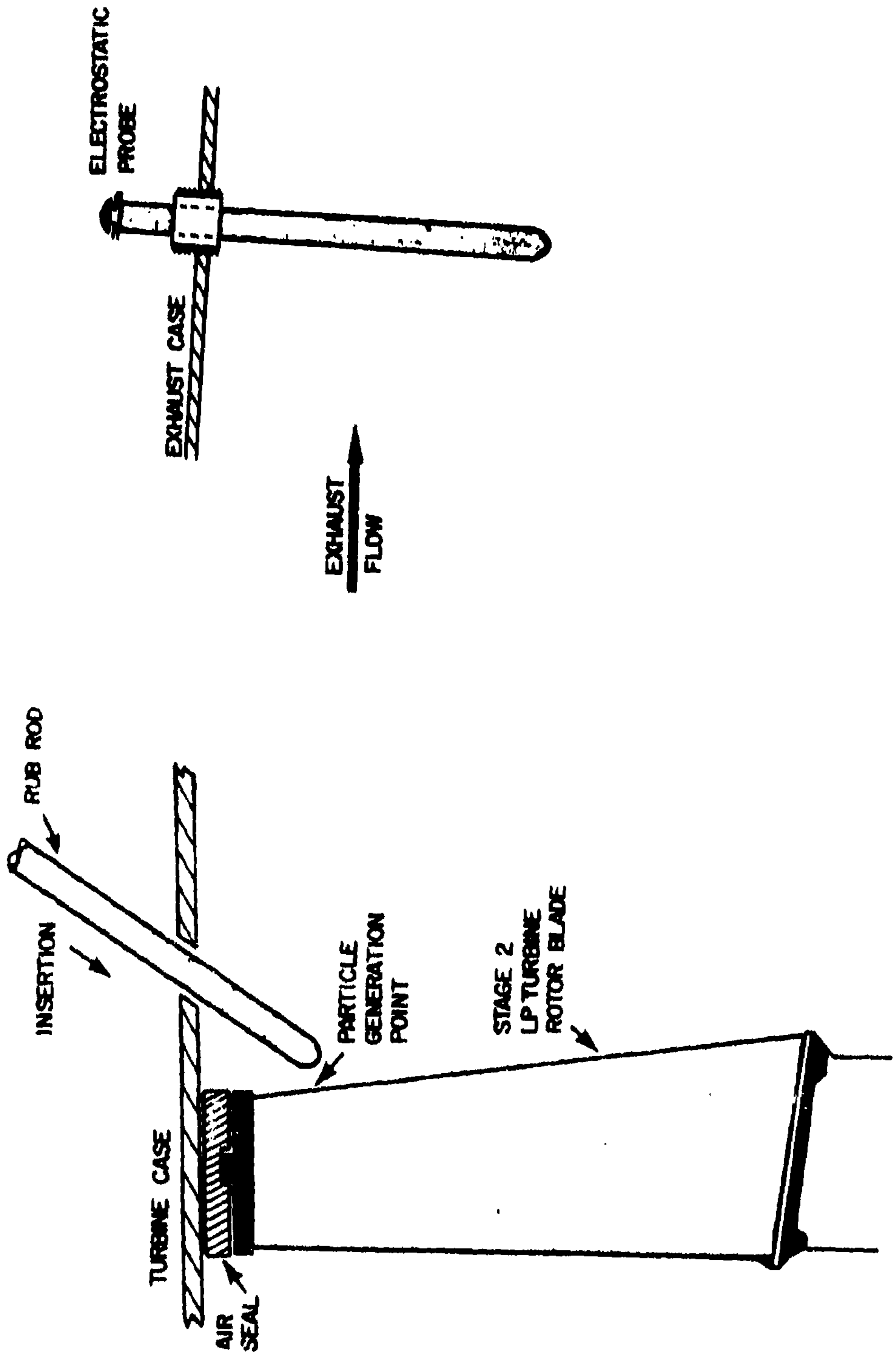


Figure 4. Rub Rod Insertion Location Into LP Turbine

Figure 5. Rub Area on Stage 2, LP Turbine

enters station 6. Then when the thrust level was reduced to idle, rotor shift allowed rub between the rod and the base area of the blades. The actual rub location is shown in the photo of Figure 6.

Particle generation due to burning or melting was achieved in the same manner as described above, except that the location was the #1 combustor can. Figure 7 is a diagram of a J57 combustor can showing the location of the test points for Tests 7 and 8. Results for Test #6 were not satisfactory as the steel rod did not melt nor did the surface oxidize sufficiently to cause the surface to peel and flake off. The distress site was therefore moved to the region indicated for Test #7 and #8, which is closer to the fuel nozzles and has less cooling air entering the combustor can. Even here, however, satisfactory results were obtained only for a non-high temperature steel material. The material used in these tests was Type 1020 cold-roll steel (same as for the rub tests) unless otherwise stated in the individual test results. A stainless steel rod exhibited some surface burn, but no particles could be seen exiting the engine. Approximately 15 grams of rod material was melted and/or burned away in the successful attempts. (This compared with about 30 grams lost in an actual case of 1st stage turbine vane burn reported in Reference 6, a case in which the probe appeared to give an indication of distress.) Particle emission in these cases was observed to be rather erratic and with particles exiting the engine in spurts. Figures 8 and 9 show that much of the material was plated out on surfaces in the transition duct and turbine stages.

A typical electrostatic probe as used in this testing is shown in Figure 10. Probes were 1/4" diameter solid 316 stainless steel rods, electrically isolated from the exhaust case by ceramic (or by teflon for those probes mounted behind the exit nozzle). Probes were inserted into the turbine exhaust flow at the positions shown in Figure 11, which also indicates the name given to each probe position. For example, probe B17 was located at axial position B and at an angular position of 17 minutes past the hour. Insertion depth in most cases was about 3 inches into the gas flow. Probe signals were transmitted by coaxial line to probe

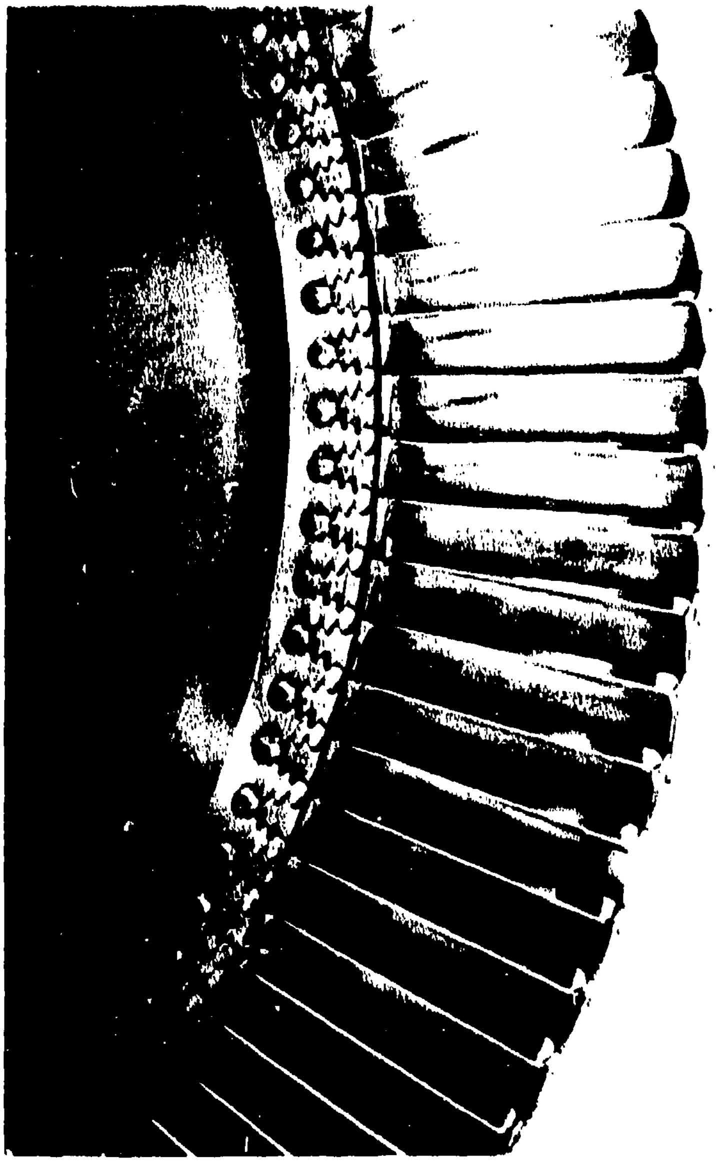


Figure 6. Rub Area on HP Turbine

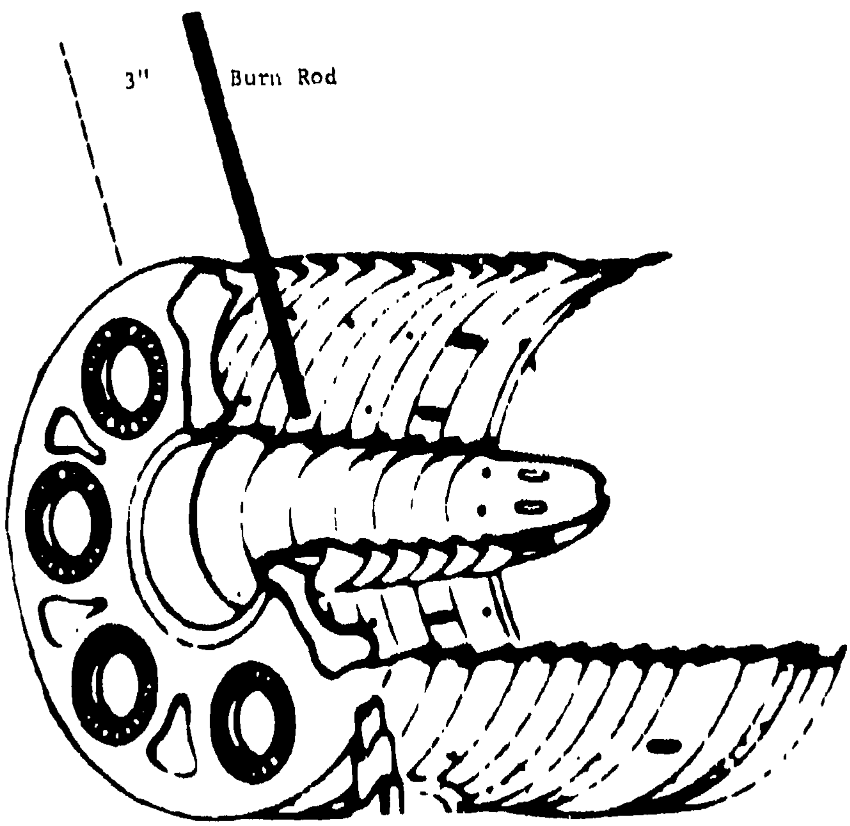


Figure 7. Combustor Can Showing Insertion Location of Burn Rod

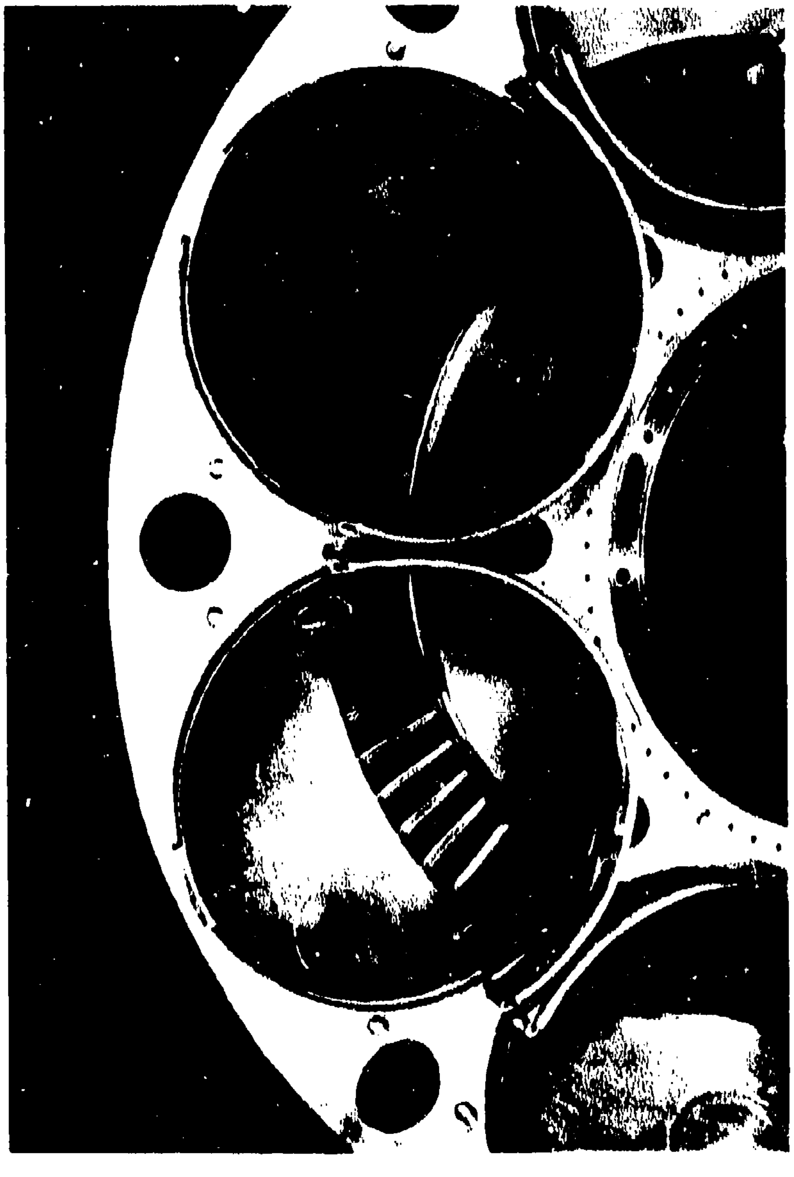


Figure 8. Plating of Burn Rod Material in Transition Duct

Figure 9. Plating of Burn Rod Material on HP Turbine Vanes

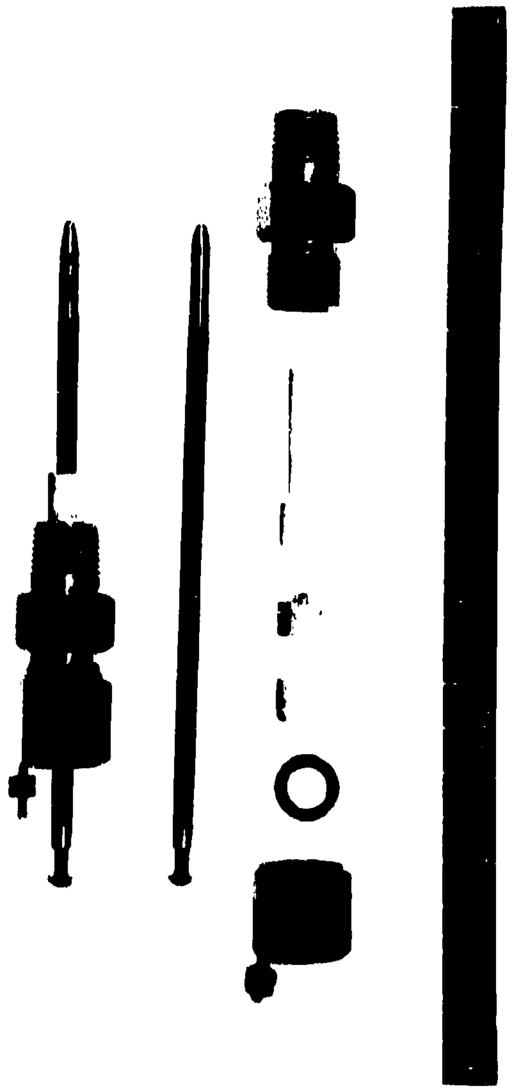
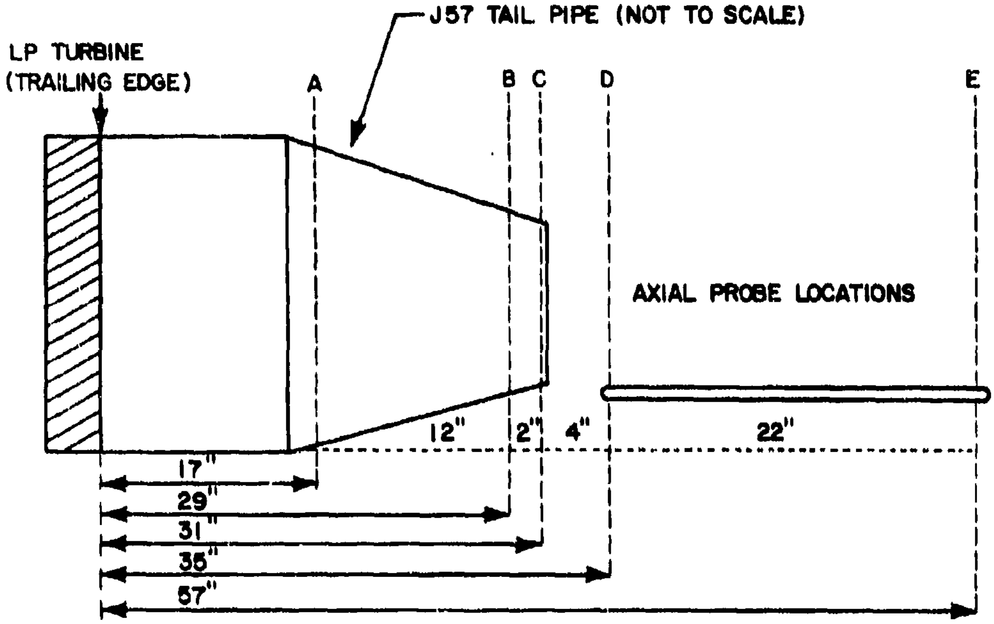
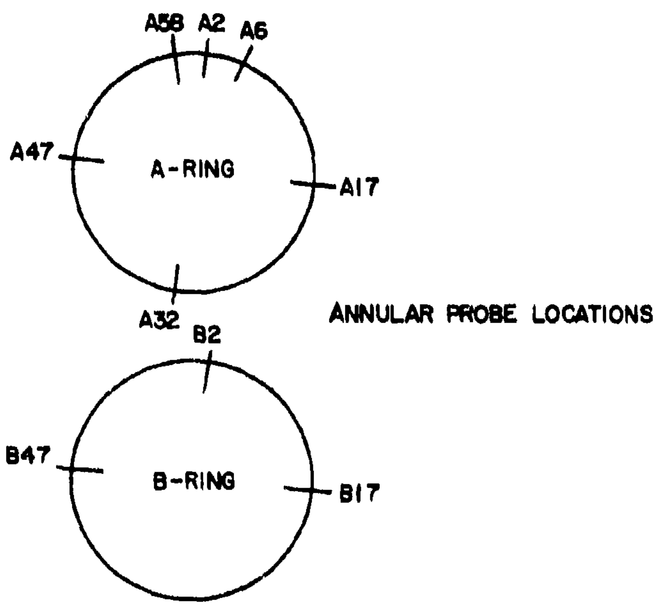


Figure 10. Typical Electrostatic Probe





C-RING: 2 CLAMP-ON PROBES; C50, C25
D-RING: D30
E-RING: E30

Figure 11. Electrostatic Probe Locations in Turbine Exhaust

electronics circuits described in Figures 12 and 13. Each electronic unit functions to count particle hits on the probe due to charge transfer and resultant voltage pulses across a carbon resistor at the unit input. The pulse is amplified, gated, and shaped for counting. Total counts accumulated during a given time period were printed on paper tape for later analysis. The units of Figure 12 (ACAPS) can analyze and record both positive and negative pulses from two different probes. In that sense it is actually a 4 channel pulse analyzer. The 10 channel pulse height units of Figure 13 (MCAs) have greater sensitivity and store counts in one of 10 channels depending on pulse amplitude. However, each MCA unit can function for pulses of one polarity from a single probe only.

Table I lists each probe position, cable, and corresponding electronic unit. Note that the configuration changed slightly from test to test. Probe positions for all tests are shown in Figure 11.

The procedure for each test was as follows:

1. operate the engine at a selected thrust setting (usually 95% normal rated thrust) and ensure reasonably steady operation;
2. record baseline probe data (counts and noise levels);
3. introduce distress and verify particle emission (to the extent possible); record all probe data and observe signal waveforms;
4. remove distress or wait until no particle emission is observed;
5. continue recording probe data to allow comparison of counts before, during, and after the test point setting;
6. terminate test and inspect test hardware;
7. analyze data for correlation of probe indications as compared to actual distress as determined by observations and post-test inspection. For example, a completely successful test would result in verified particle emission due to a successful distress simulation, an increase in probe particle counts in coincidence with distress, and documentation of signal waveforms to verify their authenticity (i.e., not pulses due to electrical interference).

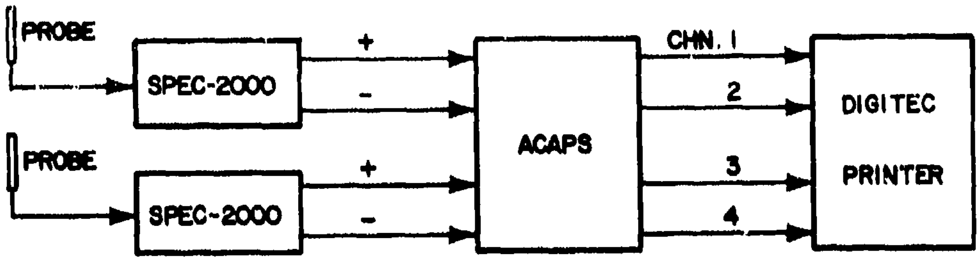


Figure 12. Automatic Counting and Printing System

The Automatic Counting and Printing System (ACAPS) will accept signals from two different probes. The SPEC-2000's are high gain amplifiers designed to count a pulse with a minimum threshold amplitude of 50 mv and a characteristic frequency of 1MHz. The ACAPS will count the number of positive and negative spikes and allow the Printer (Digitec #619) to print the information after a specific time interval. There is an overflow capability that allows the system to switch to a shorter time interval between print-outs. Three ACAPS were installed monitoring six probes.

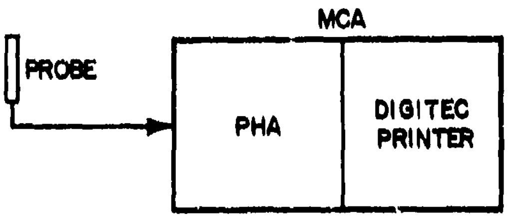


Figure 13. Multi-Channel Analyzer

The Multi-Channel Analyzer (MCA) consists of one Pulse Height Analyzer (PHA) and a Digitec Printer. This unit analyzes probe pulses of a single polarity from one probe. The PHA will total all pulses that meet the minimum threshold of 50mv and a characteristic frequency of about 1MHz. (This section is equivalent to a SPEC-2000.) The second section will analyze the lead pulse in a group of incoming pulses (showers). A shower is defined as any train of pulses with a maximum of 500 microseconds between pulses. The lead pulse is assigned a channel that is consistent with its amplitude. There are ten channels in which a lead pulse can be stored; they range from 50mv to 7 volts. At a predetermined time interval, the printer will print the total pulse count and the number of showers (lead pulses) in each channel. Three probes were monitored.

TABLE I

PROBE/CABLE ASSIGNMENT

PROBE	CABLE (TYPE)	ASSIGNMENT/REMARKS
A2	#6 (RG-62)	MCA #2
A6	#8 (RG-62)	MCA #1
A17	#1 (RG-62)	ACAPS #2, Channels 1 and 2
A32	#9 (RG-62)	ACAPS #1, Channels 3 and 4
A47	#4 (RG-62)	ACAPS #3, Channels 1 and 2
A58	#5 (RG-62)	ACAPS #1, Channels 1 and 2
B2	#12 (RG-8)	Scope Observation; I-V Traces
B17	#10 (RG-62)	ACAPS #2, Channels 3 and 4
B47	#2 (RG-62)	ACAPS #3, Channels 3 and 4
C50	#11 (RG-8)	Scope Observation, I-V Traces
	#7 (RG-62)	As of 30 Jan 74
C25	#30, 31 (25KV)	H.V. I-V Traces as of 11 Feb 74
D30	#32 (25KV)	H.V. I-V Traces until 22 Jan 74
	#13 (RG-62)	MCA #3 as of 23 Jan 74
E30	#30 (25KV)	H.V. I-V Traces until 22 Jan 74
	#14 (RG-62)	Scope Observation and I-V Traces
TC10*	#3 (RG-62)	Thermocouple probe as of 30 Jan 74 and scope observation
COMP25**	#14 (RG-62)	Installed 11 Feb 74 for I-V Traces COMP = Compressor probe

* Placed in spare thermocouple hole position (tail pipe)

** Compressor diffusor location.

SECTION III
RESULTS

The results obtained in this evaluation are subject to considerable interpretation. As a first step in presenting the test findings, a tabulated summary of preliminary results will be given which indicates how the probe data appeared to correlated with test conditions upon initial examination. However, it will be shown later (Section IV) that a more careful analysis was required to provide for proper interpretation. Therefore, case-by-case descriptions of each test will also be presented before proceeding with the analysis.

A tabulated summary of preliminary results is given in Table II. The test numbers correspond to those of Figure 2 which point out the location of the respective distress sites. The 3rd, 4th, and 5th columns of Table II list probe counts before, during, and after the intended period of simulated distress. However, the rod insertion period for some tests was not the actual period in which particles were emitted due to poor experimental control. Column 6 inidcates interesting oscilloscope waveform photographs and the corresponding figures to which the reader may refer for comments on signal characteristics, which were found to be an important factor for an accurate interpretation of the test results.

Individual test descriptions are shown in Tables III through XVI and Figures 14 through 47.

TABLE II

PRELIMINARY RESULTS

DISTRESS TEST LOCATION	PROBE COUNTS			SIGNAL PHOTOS	REMARKS
	BEFORE	DURING	AFTER		
1 LP Turb	0	0	0	Fig. 16 Fig. 17	22 Jan 74/ Rub occurred at idle after intended test period.
2 HP Turb	0	10000	0	None	23 Jan 74/ Same as above.
3a HP Turb	0	3114	0	Fig. 22 Fig. 23	25 Jan 74/ Same as above. Waveforms indicate signals as noise.
3b HP Turb	0	12	0	Fig. 26 Fig. 27	25 Jan 74/ Same as above, but waveforms appear good.
4a LP Turb	0	0	0	None	31 Jan 74/ Rub confirmed at idle; probably some rub at test point.
4b LP Turb	0	0	0	None	31 Jan 74/ Rub during proper test period.
5 LP Turb	0	467	0	Fig. 34 Fig. 35	11 Feb 74/ Proper rub period with confirmed particle emission.
6a Combustor	0	0	0	None	15 Feb 74/ No evidence of rod burn or melting
6b Combustor	35	32	0	None	15 Feb 74/ Same as 6a. Counts due to background particles or electrical interference.
7a Combustor	17	2	0	None	25 Feb 74/ S.S. rod surface had some oxidation but no significant material loss. Same as 6b.
7b Combustor	0	623	0	None	25 Feb 74/ 2" length of rod burned or melted away. Time correlation was uncertain.
8a Combustor	0	0	0	None	26 Feb 74/ 1-7/16" length of rod burned or melted away. A few sparks observed at test point.
8b Combustor	0	0	0	None	26 Feb 74/ Rod surface burn but very little material loss.
9 LP Turb	74K	107K	43K	Fig. 47	15 Mar 74/ Many counts, but all appear to be noise. All probes biased -67 volts this test only.

NOTE: Probe counts for the "During" period were counts recorded at the test point setting(s), which was usually about 95% normal rated thrust (NRT). The induced distress took place during this period, assuming the distress simulation occurred as intended, which was not the case for Tests 1 thru 4a. The "Before" and "After" periods were used for systematic checks and background data collection while the engine was operating (usually at idle).

TABLE III

ENGINE OPERATING CONDITIONS, TEST #1 (22 JAN 74)

LP2 Turbine Rub

Barometer: 29.21" Hg   *TT2: 52°F   Normal Rated Thrust: 9200 lbs.

TIME	THRUST (Lbs)	N1** (RPM)	N2*** (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 **** (°F)	REMARKS
1327	Start	-	-	-	-	-	Start. Heat engine oil.
1337	600	2100	6000	2.0	900	495	Idle check.
1340	600	2100	6000	2.0	900	500	Recheck idle.
1344	6800	5000	8400	25.5	5300	845	75% NRT check.
1350	8750	5320	8740	35.0	6800	970	95% NRT. Floating potential on probe C50 more than 100V.
1405	8600	5320	8760	35.0	6700	965	Recheck thrust setting.
1407	-	-	-	-	-	-	Advance rub rod 0.40".
1411	8400	5310	8740	34.5	6700	960	No probe counts.
[illegible]	Idle	-	-	-	-	-	Go to idle.
[illegible]	600	2000	5800	2.0	900	510	Visible sparks emitted from engine tailpipe due to rub.
[illegible]	9200	5400	8780	36.7	7300	1015	100% NRT check.
[illegible]	-	-	-	-	-	-	Advance rub rod to total depth of 0.45". No counts.
[illegible]	600	2100	6000	2.0	900	505	Idle. Cool engine oil.
[illegible]	Stop	-	-	-	-	-	Shutdown. Inspect engine.

COMMENTS: Inspection reveals rub rod worn as shown in Figure 15. Comparison with later tests indicates rub occurred at idle and upon shutdown due to forward shift in spool at thrust levels significantly above idle.

All probe systems recorded zero counts.

No recognizable particle signals, but much low-level noise observed on oscilloscope. See Figures 16 and 17.

CONCLUSIONS: No detection of particles at idle. No false counts due to observed electrical interference.

* Total temperature at station 2

** Low speed spool

*** High speed spool

**** Total temperature at station 7

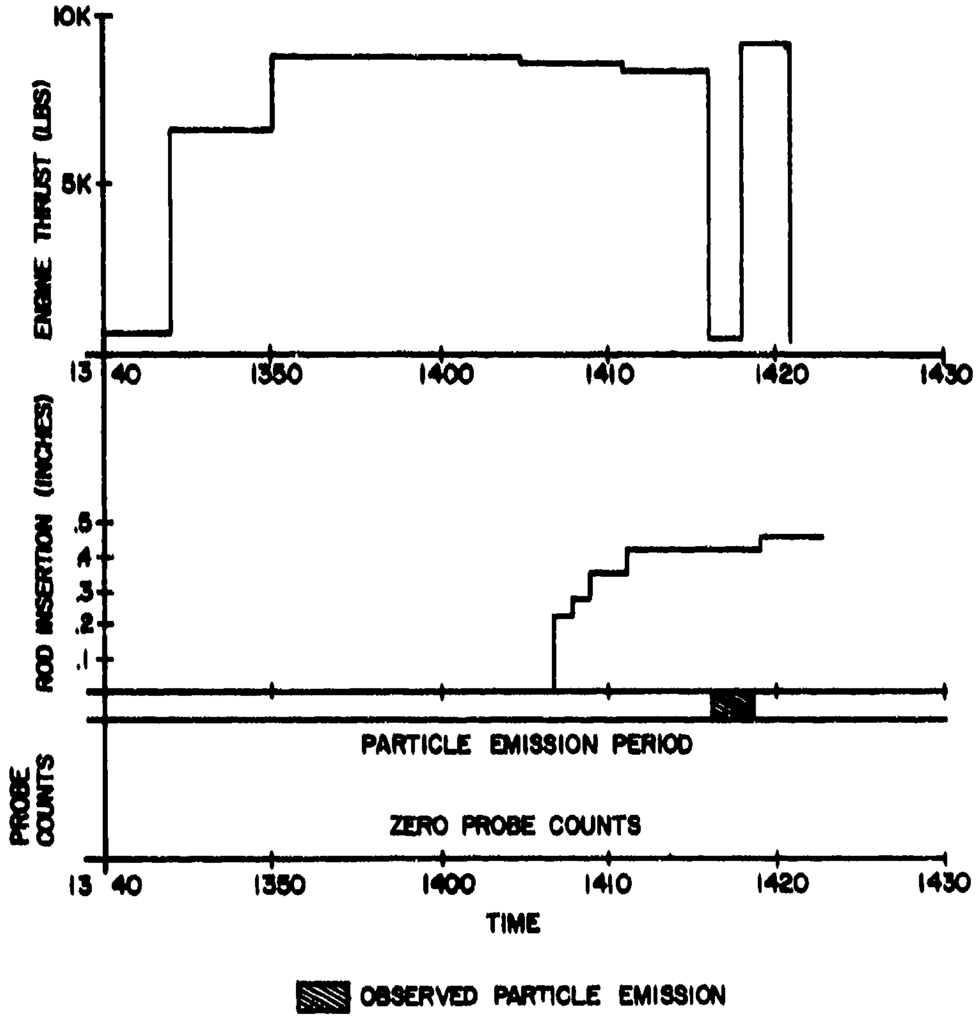


Figure 14. Time History, Test #1

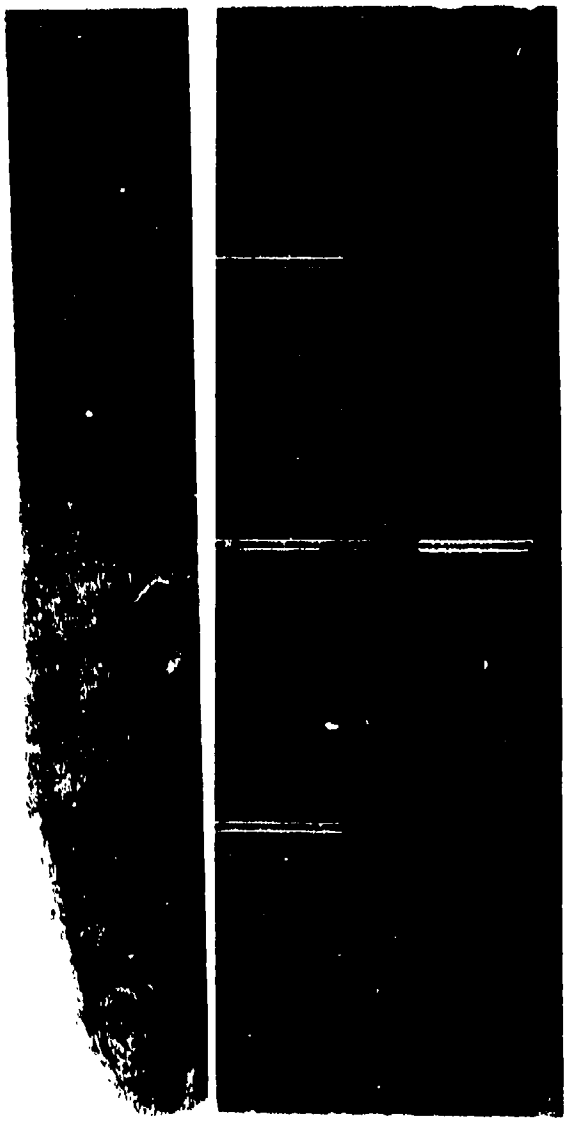
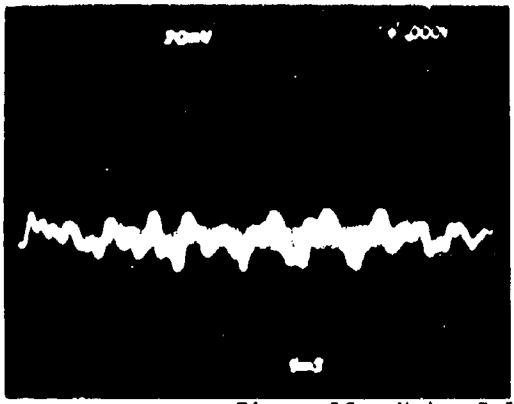


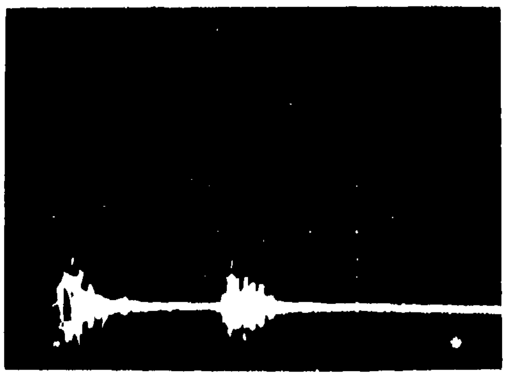
Figure 15. Rub Rod, Test #1



Test: 1
Date/Time: 22 Jan 74, PM
Engine: J57-37
Cable/Term.: RG-62/1 Megohm
Probe: A2
V/DIV: 20mv
T/DIV: 5ms

Figure 16. Noise Pulse Into 1 Mohm

Remarks: Typical low level background noise into 1MΩ termination (similar DC level fluctuations have been observed to some extent on all other engines). This type noise was not counted by the probe electronic systems, since these systems provide 93Ω termination, the characteristic cable impedance, which greatly attenuates the signal and prevents cable reflections.



Test: 1
Date/Time: 22 Jan 74, PM
Engine: J57-37
Cable/Term.: RG-8/50 ohms
Probe: B2
V/DIV: 50mv
T/DIV: 200ns

Figure 17. Noise Pulse Into 50 Ohms.

Remarks: The amplitude of these noise pulses was 50-100mv. Signals having this amplitude and high fundamental frequency were not counted due to the integration characteristics of the pulse analyzer for frequencies above 1MHz. (These pulses could be counted only if the amplitude were much larger - about 3 volts). The origin of the signals was not determined, although they are characteristic of inductive transient electrical interference.

TABLE IV

ENGINE OPERATING CONDITIONS, TEST #2 (23 JAN 74)

HP1 Turbine Rub

Barometer: 29.26" Hg.			TT2: 39°F			Normal Rated Thrust: 9700 Lbs.	
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1419	Start	-	-	-	-	-	Start. Idle.
1420	2400	-	-	-	-	-	Allow oil to heat.
1421	4500	-	-	-	-	-	"
1423	6000	-	-	-	-	-	"
1426	5070	4700	8160	20.5	4100	725	
1430	700	2040	5800	2.0	1000	490	Idle.
1434	-	-	-	-	-	-	Go to 90%NRT.
1435	8600	5200	8580	34.8	6500	950	Maintain 90%NRT.
1440	-	-	-	-	-	-	Advance rub rod slowly up to .075"
1442	-	-	-	-	-	-	Advance rod .075".
1445	-	-	-	-	-	-	Advance rod .030".
1449	-	-	-	-	-	-	Advance rod .015".
1451	-	-	-	-	-	-	Advance rod .015".
1453	8700	5260	8640	34.8	6600	935	Retract rub rod.
1455	Idle	-	-	-	-	-	Got to Idle.
1457	Stop	-	-	-	-	-	Shutdown.

COMMENTS: Rub was minor and believed to have occurred only at idle. See photo of rub rod in Figure 19.

Unable to document signal waveforms to confirm origin.

The large number of observed counts occurred at the intended thrust setting. The possibility of proper probe detection cannot be ruled out, even though the rub was minor and was not believed to have occurred at the intended setting. Alternative explanations are background counts or noise counts due to electrical interference.

CONCLUSIONS: Probe counts occurred in the proper time period if one assumes the rub occurred as intended. However, evidence indicated that rub began when the thrust was reduced to the idle setting. There were no confirming particle sparks or probe signal waveform documentation.

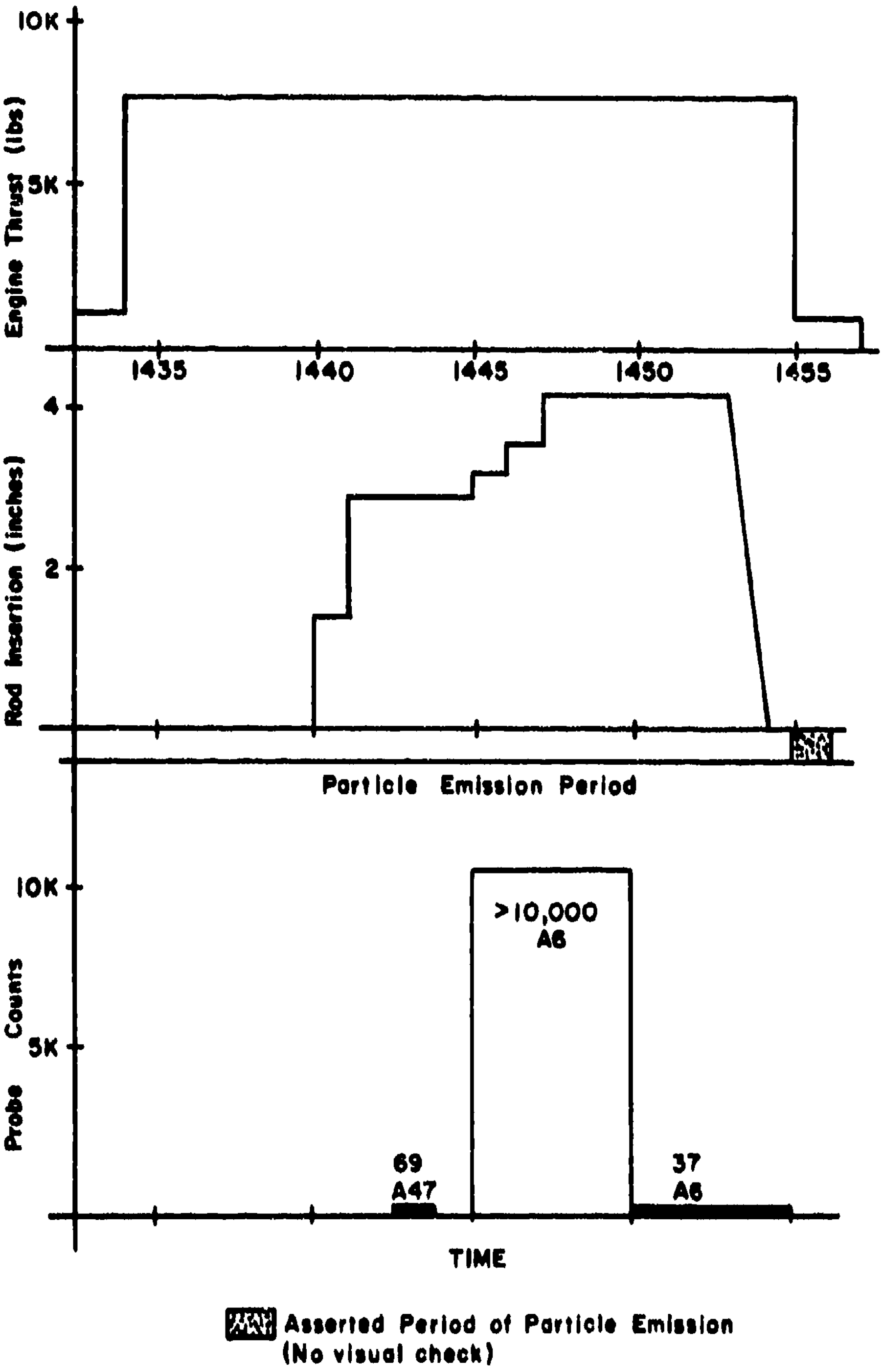


Figure 18. Time History, Test #2

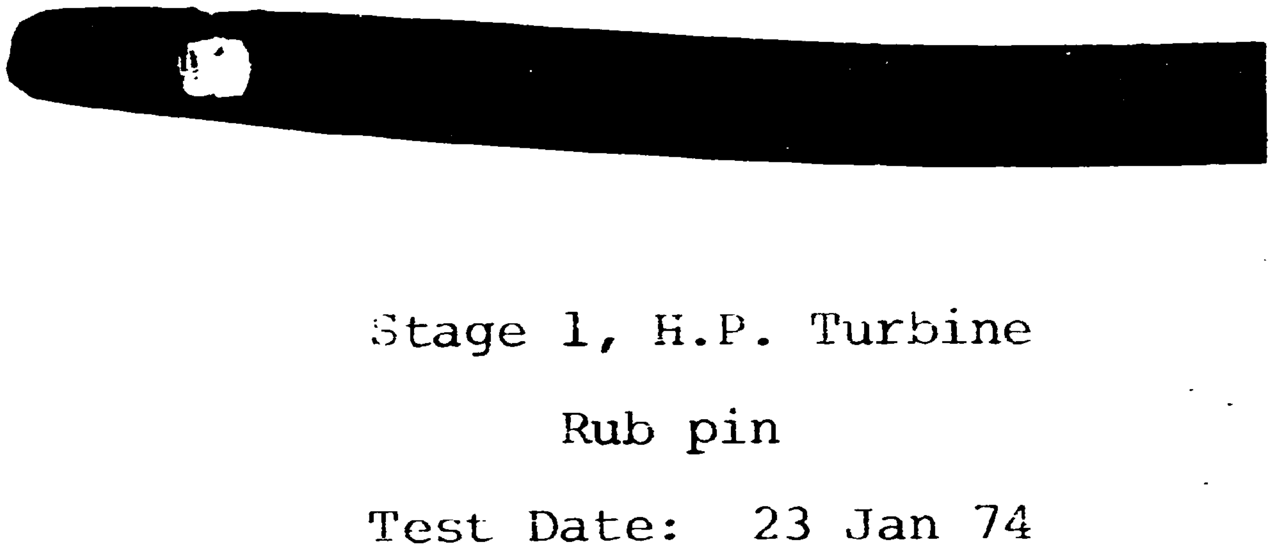


Figure 19. Rub Rod, Test #2

TABLE V
ENGINE OPERATING CONDITIONS, TEST #3a (25 JAN 74)

HP1 Turbine Rub

Barometer: 29.44"Hg				TT2: 35°F			Normal Rated Thrust: 10000 Lbs
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1021	Start	-	-	-	-	-	Start. Idle.
1023	6400	-	-	-	-	-	Allow oil to heat.
1029	Idle	-	-	-	-	-	Go to idle.
1030	600	2160	6000	-	1000	450	
1034	10000	-	-	-	-	-	Accelerate to 10000 Lbs.
1036	9000	5260	8640	-	7000	955	Maintain 9000 Lbs.
1039	-	-	-	-	-	-	Start rub rod insertion.
1040	-	-	-	-	-	-	Total depth .12".
1041	-	-	-	-	-	-	Total depth .15"
1042	-	-	-	-	-	-	Total depth .18".
1044	-	-	-	-	-	-	Total depth .24".
1045	-	-	-	-	-	-	Total depth .30".
1047	-	-	-	-	-	-	Total depth .36".
1049	9000	5300	8680	-	7000	950	Recheck thrust setting.
1050	-	-	-	-	-	-	Total depth .42".
1051	-	-	-	-	-	-	Total depth .48".
1054	-	-	-	-	-	-	Total depth .60".
1057	-	-	-	-	-	-	Total depth .66".
1100	600	2140	6000	-	1000	460	Sparks observed.
1105	-	-	-	-	-	-	Total depth .72". Sparks.
1108	Stop	-	-	-	-	-	Shutdown with rod still in.

COMMENTS: Rub on rod was as shown in Figure 21. Visible particle emission observed at idle. No other rub was judged to have occurred, based upon inspection of test hardware. 915 counts were recorded on probe D30 in the 5 minute period just after idle, but waveforms indicate electrical interference. Also, the counts recorded during the test point setting (90%NRT) were believed due to interference. See the waveform photos and comments of Figures 22 and 23.

CONCLUSIONS: Counts were recorded at idle during rub, but waveforms indicate signals due to electrical interference.

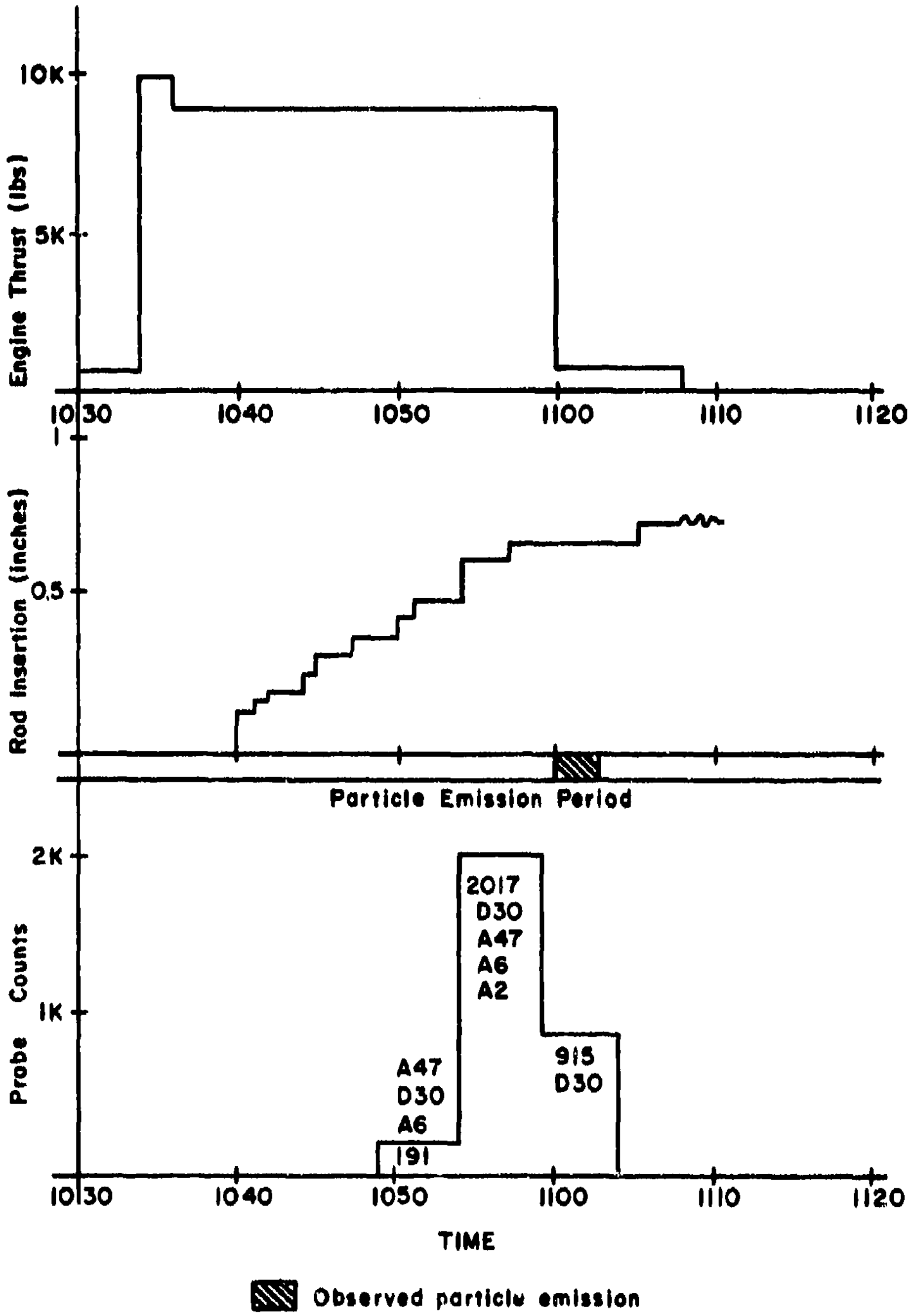


Figure 20. Time History, Test #3a

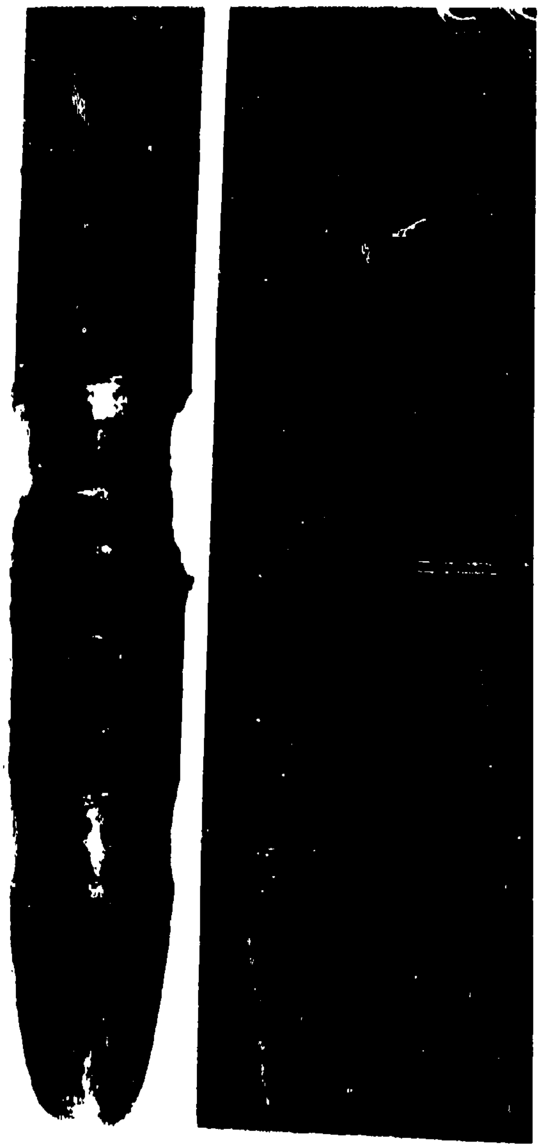
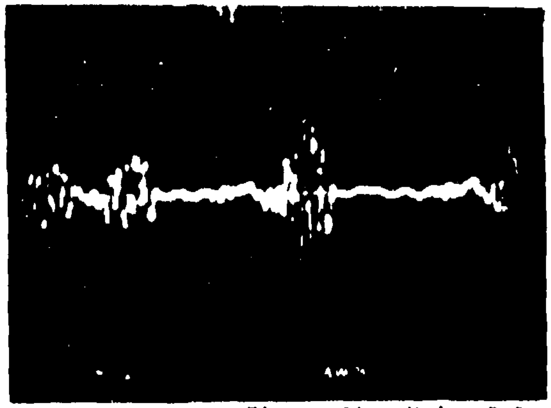


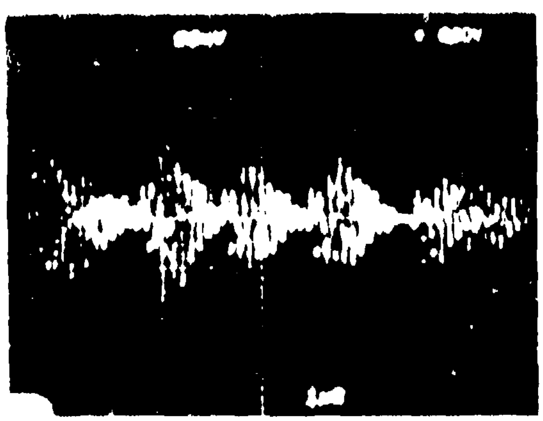
Figure 21. Rub Rod, Test #3a



Test: 3a
Date/Time: 25 Jan 74, 1055
Engine: J57-37
Cable/Term.: RG-62/93 ohms
Probe: A6
V/Div: 50mv
T/Div: 1 microsec.

Figure 22. Noise Pulses, Test #3a

Remarks: Probe A6 was connected to MCA#1. MCA#1 recorded one shower and a total of six positive pulses. The signals have the general appearance of electrical interference. The oscillatory pulses in this case arrived at irregular intervals. The origin of these signals was not determined.



Test: 3a
Date/Time: 25 Jan 74, 1100
Engine: J57-37
Cable/Term.: RG-62/93 ohms
Probe: A2
V/Div: 50mv
T/Div: 1 microsec.

Figure 23. Noise Pulses 6 MHz, Test #3a

Remarks: Probe A2 was connected to MCA#2. During this time MCA#2 recorded one shower and a total of two positive pulses. These signals are not normal J57 pulses nor are they typical random noise bursts. Their cyclic rate (6MHz) appears to be from an A.M. source.

TABLE VI

ENGINE OPERATING CONDITIONS, TEST #3b (25 JAN 74)

HPl Turbine Rub

Barometer: 29.43" Hg TT2: 45°F Normal Rated Thrust: 9600 Lbs

TIME	THRUST (lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1336	Start	-	-	-	-	-	Start. Idle.
1339	4200	-	-	-	-	-	Allow oil to heat.
1343	6400	5640	8180	-	4200	725	Allow oil to heat.
1345	750	-	-	-	-	-	Idle.
1347	800	5180	6000	-	1000	470	Idle.
1348	-	-	-	-	-	-	Start rub rod insertion.
1349	-	-	-	-	-	-	Total depth .06".
1350	-	-	-	-	-	-	Total depth .12".
1352	-	-	-	-	-	-	Total depth .18".
1354	-	-	-	-	-	-	Total depth .24".
1356	-	-	-	-	-	-	Total depth .30".
1358	-	-	-	-	-	-	Total depth .48".
1405	-	-	-	-	-	-	Total depth .72".
1407	700	2140	6000	-	1000	495	Retract rub rod.
1410	-	-	-	-	-	-	Rod retracted.
1412	-	-	-	-	-	-	Total depth .18".
1413	9000	-	-	-	-	-	Accelerate to 9000 Lbs. large probe spike observed.
1415	9000	5300	8700	-	7000	975	Maintain 9000 Lbs.
1416	-	-	-	-	-	-	Total depth .30".
1418	Idle	-	-	-	-	-	Go to idle. Sparks observed.
1422	9000	-	-	-	-	-	Go to 9000 Lbs.
1423	-	-	-	-	-	-	Total depth .42".
1425	Idle	-	-	-	-	-	Go to idle. Rub heard.
1428	-	-	-	-	-	-	Total depth .54".
1429	9000	-	-	-	-	-	Go to 9000 Lbs.
1430	-	-	-	-	-	-	Total depth .72".
1431	Idle	-	-	-	-	-	Go to idle. Rod was twisted manually to give many sparks.
1440	Stop	-	-	-	-	-	Shut down.

COMMENTS: Rub was too minor to permit accurate measure of material rubbed away. (See photo of rod in Figure 24.) Particle emission observed at idle and when rod was twisted to produce rub (also at idle). No probe counts due to rub observed at idle. At time 1413, three counts were recorded on probe B17. Figure 26 shows that at least one of these signals was of the variety normally observed for J57 engines. Whether this signal is due to engine acceleration and resultant background particle emission or due to another cause could not be determined. This signal was not due to rub, as the rub rod was in the retracted position at this time.

At time 1430, nine counts were recorded on probe D30. The appearance of these signals (Figure 27) is not clearly "random" noise, but is more characteristic of electrical interference from an outside source.

CONCLUSIONS: No detection of confirmed rub with particle emission at idle. The "classical" J57 type signal is believed due to normal background. Other counts believed due to electrical interference.

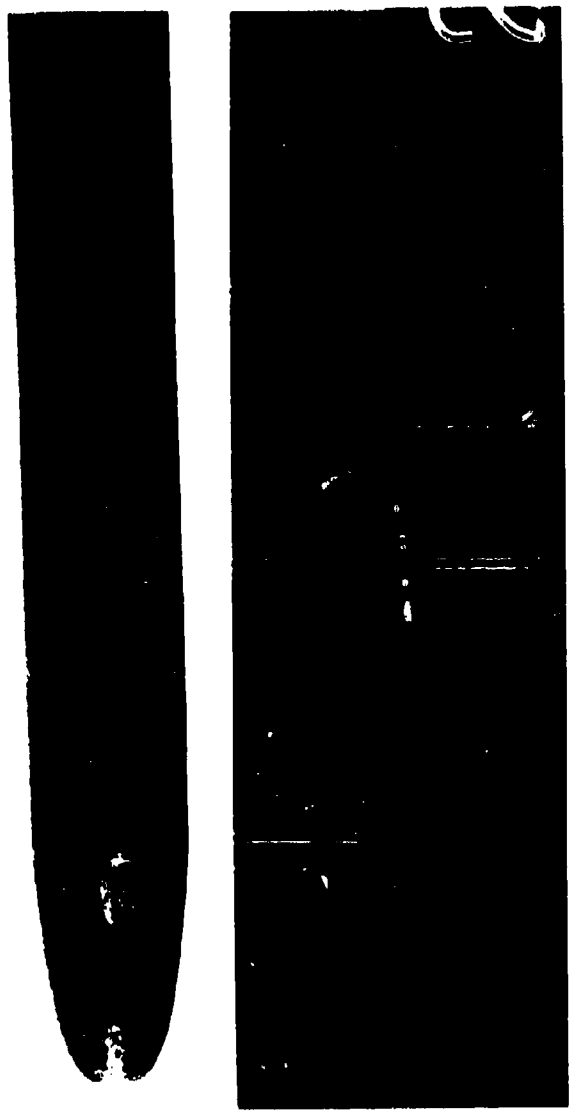


Figure 24. Rub Rod, Test #3b

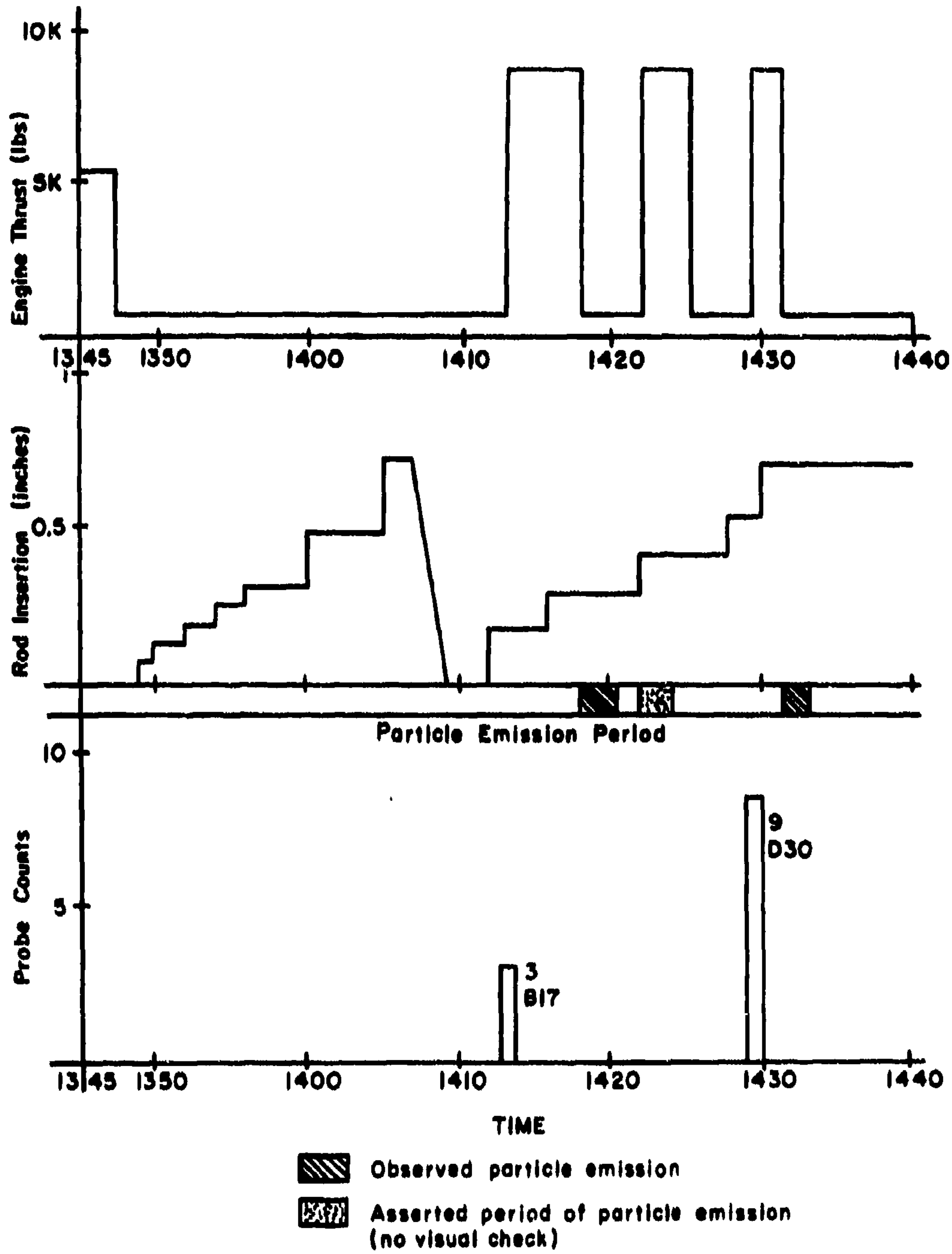
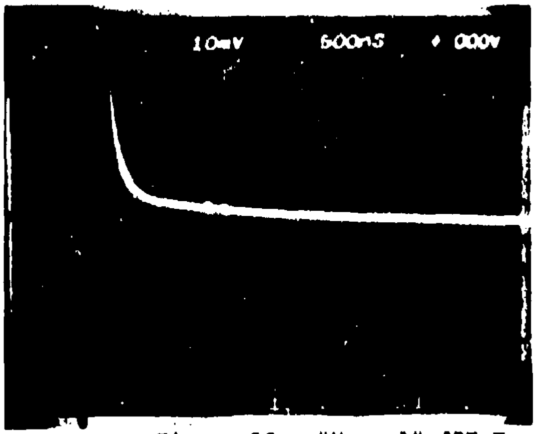


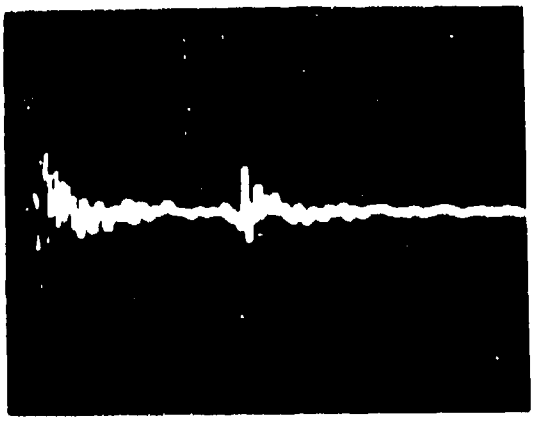
Figure 25. Time History, Test #3b



Test: 3b
Date/Time: 25 Jan 74, 1412
Engine: J57-37
Cable/Term.: RG-62/93 ohms
Probe: B17
V/Div: 10mv
T/Div: .5 microsec.

Figure 26. "Normal" J57 Type Pulse, Test #3b

Remarks: Probe B17 was connected to ACAPS#2. (This type of pulse has been observed on other J57s.) The rub-rod was inserted and the J57 was accelerated to a thrust of 9000lbs. This pulse was recorded about 30 seconds after acceleration and the ACAPS #2 recorded three counts. This monopolar pulse implies a net charge transfer to the probe, and may therefore be interpreted as charged particle detection, although a proposed alternative explanation is static discharge due to arcing at the probe surface.



Test: 3b
Date/Time: 25 Jan 74, 1430
Engine: J57-37
Cable/Term.: RG-62/93 ohms
Probe: B17
V/Div: 10mv
T/Div: .5 microsec.

Figure 27. Noise Pulse, Test #3b

Remarks: These pulses were recorded when the J57 was returned to idle condition. During this time MCA#3 also recorded nine pulses. The origin of these pulses could not be determined, although the oscillatory appearance is characteristic of transient electrical interference.

TABLE VII

ENGINE OPERATING CONDITIONS, TEST #4a (31 Jan 74)

LP2 Turbine Rub

Barometer: 29.11"Hg				TT2: 53°F			Normal Rated Thrust: 9000 Lbs
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1252	Start	-	-	-	-	-	Start. Idle.
1255	6000	-	-	-	-	-	Allow oil to heat.
1300	10200	-	-	-	-	-	Wide open throttle.
1304	600	2100	6000	2.0	1000	500	Idle.
1313	8500	-	-	-	-	-	Accelerate to 95%NRT.
1317	8500	5300	8740	34.2	6700	960	Maintain 95%NRT.
1324	-	-	-	-	-	-	Start rub rod insertion.
1326	-	-	-	-	-	-	Total depth .38".
1327	-	-	-	-	-	-	Total depth .42".
1328	-	-	-	-	-	-	Total depth .46".
1329	-	-	-	-	-	-	Total depth .49".
1330	-	-	-	-	-	-	Total depth .53".
1332	-	-	-	-	-	-	Total depth .57".
1336	Idle	-	-	-	-	-	Go to idle. Check rod drive.
1340	Stop	-	-	-	-	-	Shutdown with rod still in.

COMMENTS: Moderate rub (see Figure 29) produced after test point upon retarding engine throttle to idle; particle emission visually confirmed. No detection by probes.

Since the rub rod was inserted for a total depth of about 0.6", results of test #5 (where the same reference depth was used) indicated that some rub (about 0.1") would have occurred at the test point. The flaired tip appearance produced at 95%NRT (e.g. see Figure 31) would then be ground away by rub at idle, since the rod was not retracted before retarding the throttle.

CONCLUSIONS: No detection of rub particles at idle or test point. No probe counts.

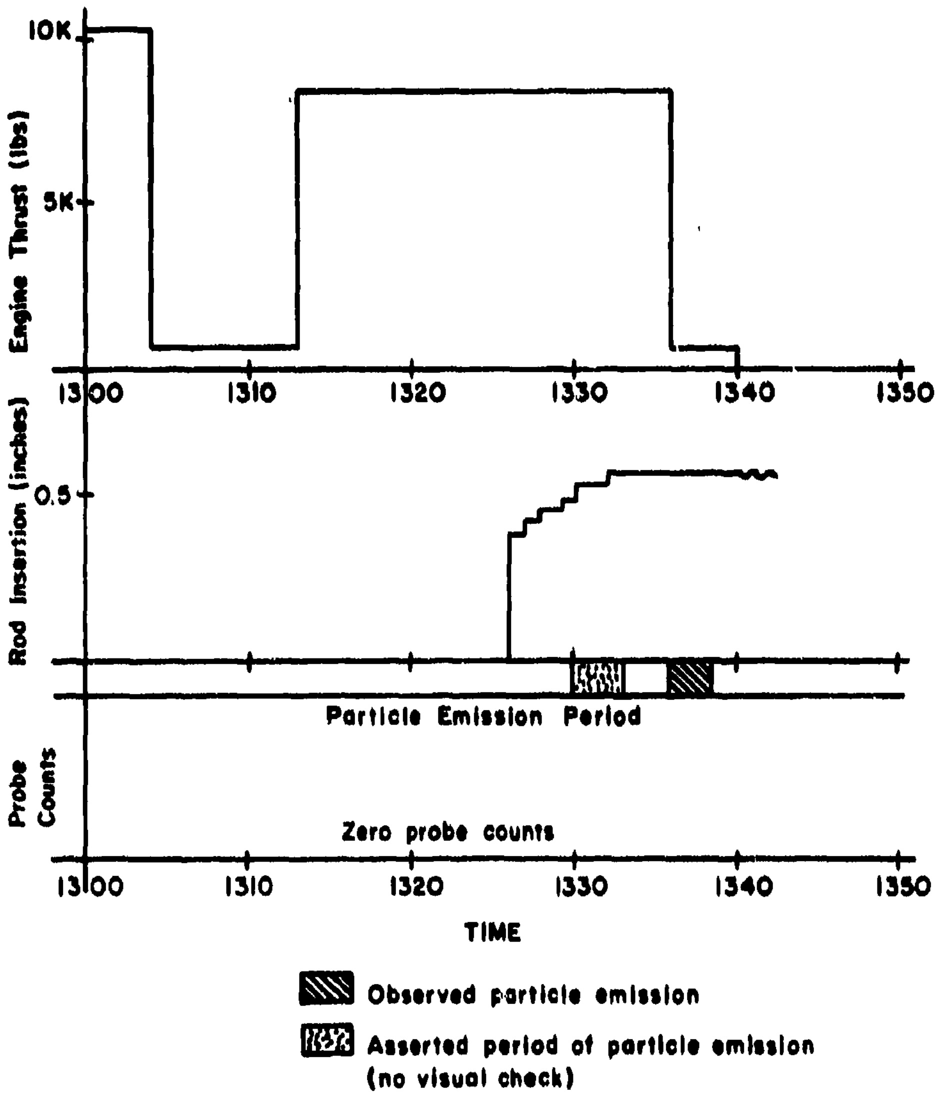


Figure 28. Time History, Test #4a

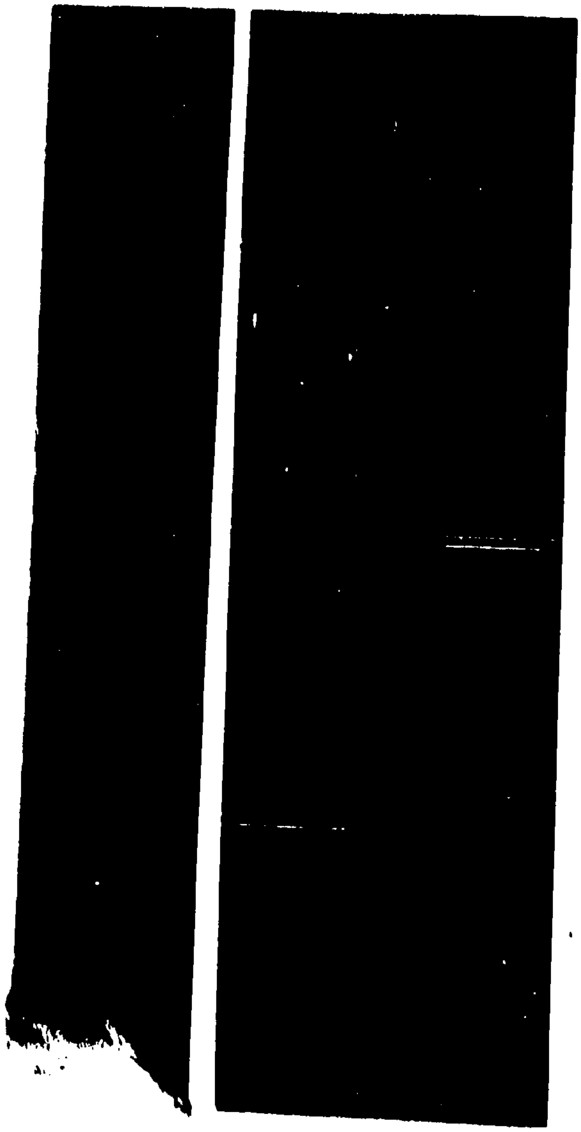


Figure 29. Rub Rod, Test #4a

TABLE VIII

ENGINE OPERATING CONDITIONS, TEST #4b (31 JAN 74)

LP2 Turbine Rub

Barometer: 29.11"Hg			TT2: 51°F			Normal Rated Thrust: 9000 Lbs	
TIME	THRUST (lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1430	Start	-	-	-	-	-	Start. Idle.
1432	7000	-	-	-	-	-	Allow oil to heat.
1435	Idle	-	-	-	-	-	Go to idle.
1436	700	2200	6060	2.2	900	498	Idle.
1438	8500	-	-	-	-	-	Go to 8500 Lbs.
1439	8400	5300	8660	33.5	6800	960	Maintain 8500 Lbs.
1440	-	-	-	-	-	-	Start rub rod insertion.
1442	-	-	-	-	-	-	Total depth .36".
1443	-	-	-	-	-	-	Total depth .40". Begin slow continuous insertion.
1447	8550	5300	8720	34.5	6800	945	Recheck thrust setting.
1457	-	-	-	-	-	-	Stop rod insertion. Total depth 1.14".
1458	-	-	-	-	-	-	Retract rod to .57".
1500	Idle	-	-	-	-	-	Go to idle. No rub sparks.
1504	Stop	-	-	-	-	-	Shutdown. No sparks.

COMMENTS: Significant rub produced at 95%NRT. (See Figure 31.) Approximately 3.5 grams of material lost. No probe counts.

CONCLUSIONS: No probe detection of rub at test point. Zero probe counts.

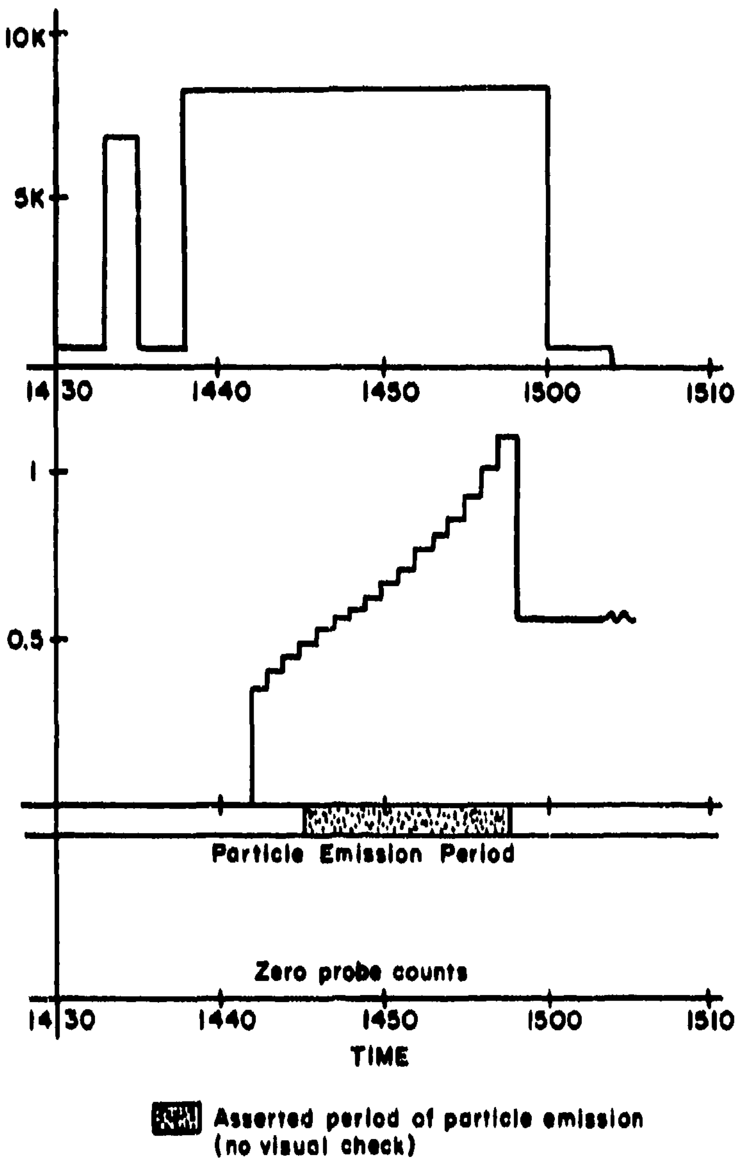


Figure 30. Time History, Test #4b

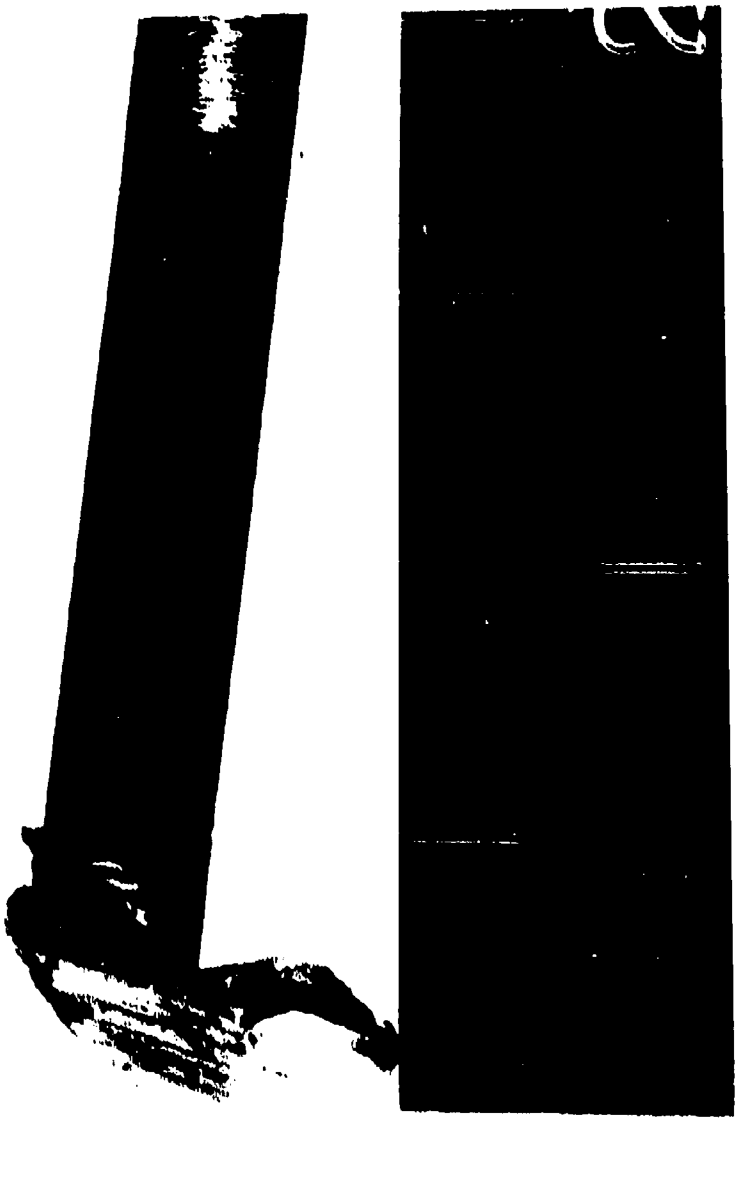


Figure 31. Rub Rod, Test #4b

TABLE IX

ENGINE OPERATING CONDITIONS, TEST #5 (11 FEB 74)

LP2 Turbine Rub

Barometer: 29.28"Hg TT2: 20°F Normal Rated Thrust: 10500 Lbs

TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
0913	Start	-	-	-	-	-	Start. Idle.
0915	3000	-	-	-	-	-	Allow oil to heat.
0920	6000	4740	8100	24.5	4600	705	Allow oil to heat.
0923	Idle	-	-	-	-	-	Go to idle.
0927	10000	-	-	-	-	-	Go to 10000 Lbs.
0929	9800	5400	8700	42.2	7700	975	Maintain thrust.
0930	-	-	-	-	-	-	Start rub rod insertion. Total depth .29".
0931	-	-	-	-	-	-	Total depth .36".
0933	-	-	-	-	-	-	Total depth .44".
0935	-	-	-	-	-	-	Total depth .51". Rub sparks observed.
0941	-	-	-	-	-	-	Total depth .59".
0942	-	-	-	-	-	-	Sparks observed intermittently over 60 sec period.
0945	9800	5400	8700	42.3	7700	970	Recheck thrust setting.
0947	-	-	-	-	-	-	Total depth .67".
0948	-	-	-	-	-	-	Rub sparks observed.
0952	-	-	-	-	-	-	Total depth .74".
0955	-	-	-	-	-	-	Total depth .86".
0958	-	-	-	-	-	-	Retract rub rod.
1001	Idle	-	-	-	-	-	Go to idle. No sparks.
1006	Stop	-	-	-	-	-	Shutdown. No sparks.

COMMENTS: Approximately 0.4 grams of rub rod material was rubbed away at the test point setting of 95%NRT. (see photo of rod in Figure 32.) All counts occurred at the test point setting. No signal waveform photos were taken in direct correlation with these counts. The photos of Figures 34 and 35 are typical of what was seen on the scope, though not necessarily at the time the counts were recorded nor on the same probe.

The 104 counts on probe A47 and B47 at time 0928-0929 are not believed due to rub simulation, since the insertion depth was not sufficient then to produce rub. These counts are thought to correlate with transient electrical interference generated during engine acceleration. Particle emission sparks were first observed at 0935 when the rod insertion depth was about 0.5". Sparks [illegible] observed intermittently during insertion over the next 13 minutes. The 361 count[illegible] on probe A47 at time 0941 did occur during the particle emission period.

CONCLUSIONS: Probe detection of rub appears satisfactory for majority of counts, although inconsistencies exist for other counts and at other times of rub when no counts were recorded. No confirming signal wave for photos were obtained of the pulses that produced the counts, although photos were obtained of typical pulses observed on the oscilloscope.

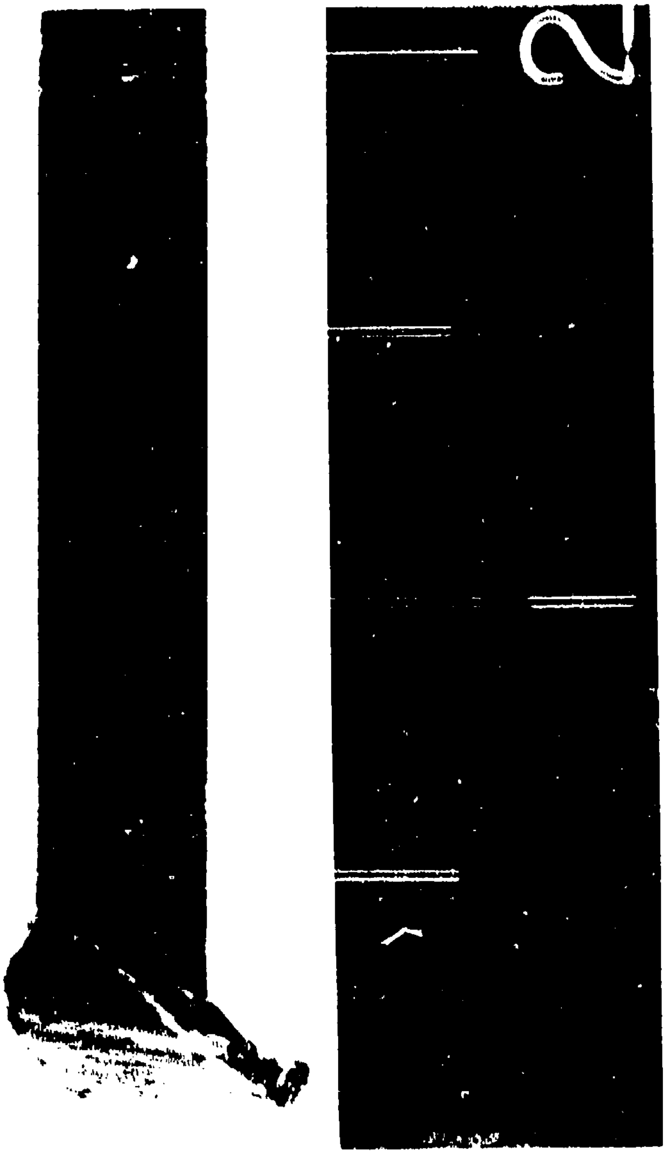


Figure 32. Rub Rod, Test #5

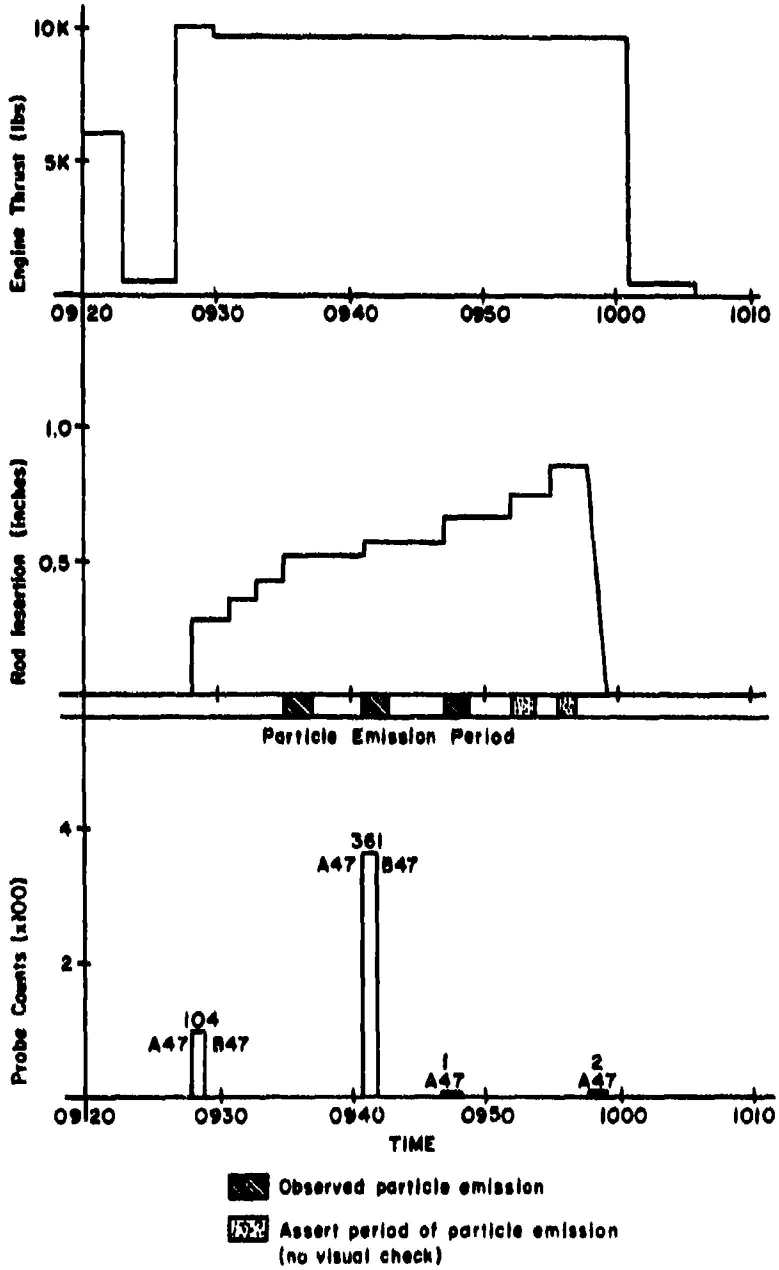
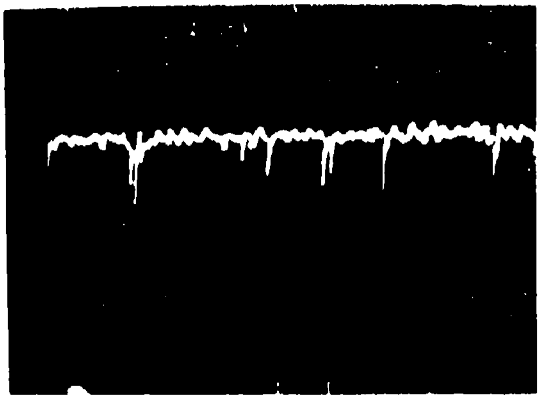


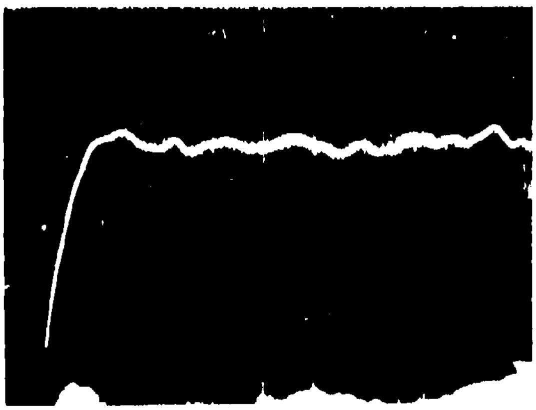
Figure 33. Time History, Test #5



Test: 5
Date/Time: 11 Feb 74, 1030
Engine: J57-37
Cable/Term.; RG-62/1 Megohm
Probe: A6
V/Div: 100mv/AC coupled
T/Div: 20ms

Figure 34. Negative Pulses Into 1 Mohm, Test #5

Remarks: Probe A6 was connected to MCA#1. The MCA#1 did not count these pulses because it was set to count positive pulses. Also, the amplitude was less than 50mv when the cable was terminated into 93 ohms. This photo shows the type of signals seen during rub-rod insertion, though similar pulses were observed during non-distress periods. (See also Single trace below.)



Test: 5
Date/Time: 11 Feb 74, 1030
Engine: J57-37
Cable/Term.: RG-62/1 Megohm
Probe: A6
V/Div: 50mv/AC coupled
T/Div: 2ms

Figure 35. Negative Pulse Into 1 Mohm (Expanded), Test #5

Remarks: This single negative pulse was obtained at 95% NRT and with the probe terminated into 1 Megohm. The number of pulses decreased upon returning to Idle. As net charge is implied by this monopolar pulse, the signal may be interpreted as due to charged particle impact with the probe. However, a much larger amplitude (more charge on the particle) would be necessary to trigger the pulse counting circuit, which incorporates 93 ohm terminations.

TABLE X

ENGINE OPERATING CONDITIONS, TEST #6a (15 FEB 74)

Combustor Overtemp

Barometer: 29.44"Hg TT2: 25°F Normal Rated Thrust: 10400 Lbs

TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1000	Start	-	-	-	-	-	Start. Idle.
1004	6000	-	-	-	-	-	Allow oil to heat.
1008	7400	4740	8160	24.5	4700	740	
1011	Idle	-	-	-	-	-	Go to idle.
1012	600	2280	6100	3.0	1000	430	Idle.
1017	9500	-	-	-	-	-	Go to 9500 Lbs.
1020	9800	5400	8740	42.0	7800	975	Maintain 9800 Lbs.
1025	9800	-	-	-	-	-	Maintain.
1027	-	-	-	-	-	-	Begin continuous burn rod insertion.
1029	-	-	-	-	-	-	Stop insertion. Total 2.5". No sparks observed.
1034	9600	5380	8740	41.5	7600	965	Recheck thrust.
1035	-	-	-	-	-	-	Retract burn rod.
1036	Idle	-	-	-	-	-	Go to idle.
1039	Stop	-	-	-	-	-	Shutdown.

COMMENTS: No observed burn or melting of rod.
No probe counts.

CONCLUSIONS: No distress. No probe counts.

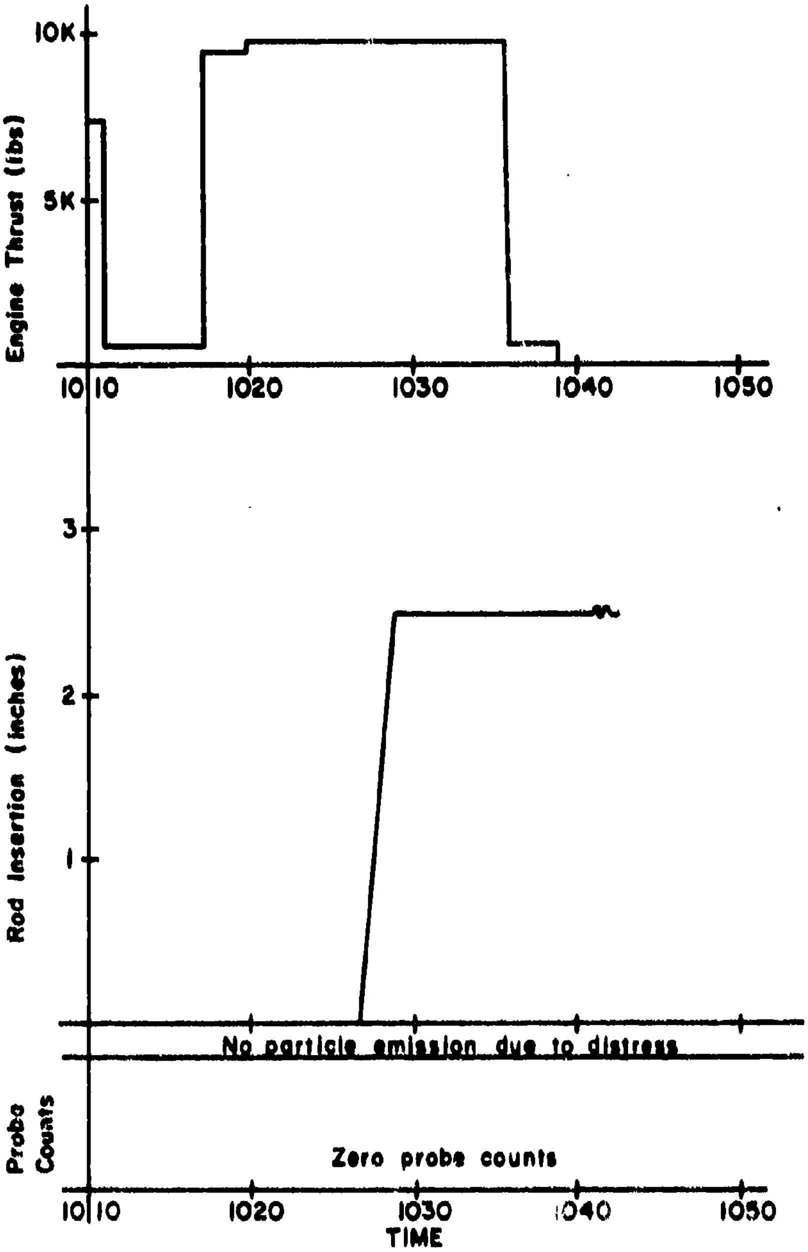


Figure 36. Time History, Test #6a

TABLE XI

ENGINE OPERATING CONDITIONS, TEST #6b (15 FEB 74)

Combustor Overtemp

Barometer: 29.42"Hg				TT2: 35°F			Normal Rated Thrust: 10000 Lbs
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1351	Start	-	-	-	-	-	Start. Idle.
1356	6500	-	-	-	-	-	Allow oil to heat.
1400	5500	4700	8160	22.0	4450	725	
1402	Idle	-	-	-	-	-	Go to idle.
1404	9500	-	-	-	-	-	Go to 9500 Lbs.
1410	9500	5400	8800	40.5	7700	985	Maintain 9500 Lbs.
1415	-	-	-	-	-	-	Begin continuous burn rod insertion.
1417	-	-	-	-	-	-	Stop insertion. Depth 2.64".
1420	-	-	-	-	-	-	Possibly one spark observed.
1424	9500	5400	8800	40.3	7600	980	Recheck thrust setting.
1426	Idle	-	-	-	-	-	Go to idle. No sparks.
1430	Stop	-	-	-	-	-	Shutdown.

COMMENTS: No surface burn of rod. Insertion position too close to combustor exit where cooling is greatest. (Distress point moved to position 7 shown in Figure 2.)

Counts recorded before and during the test period must be noise or background particle emission. No documentation of these signals to verify their origin.

CONCLUSIONS: No distress. False counts or background particles responsible for counts recorded.

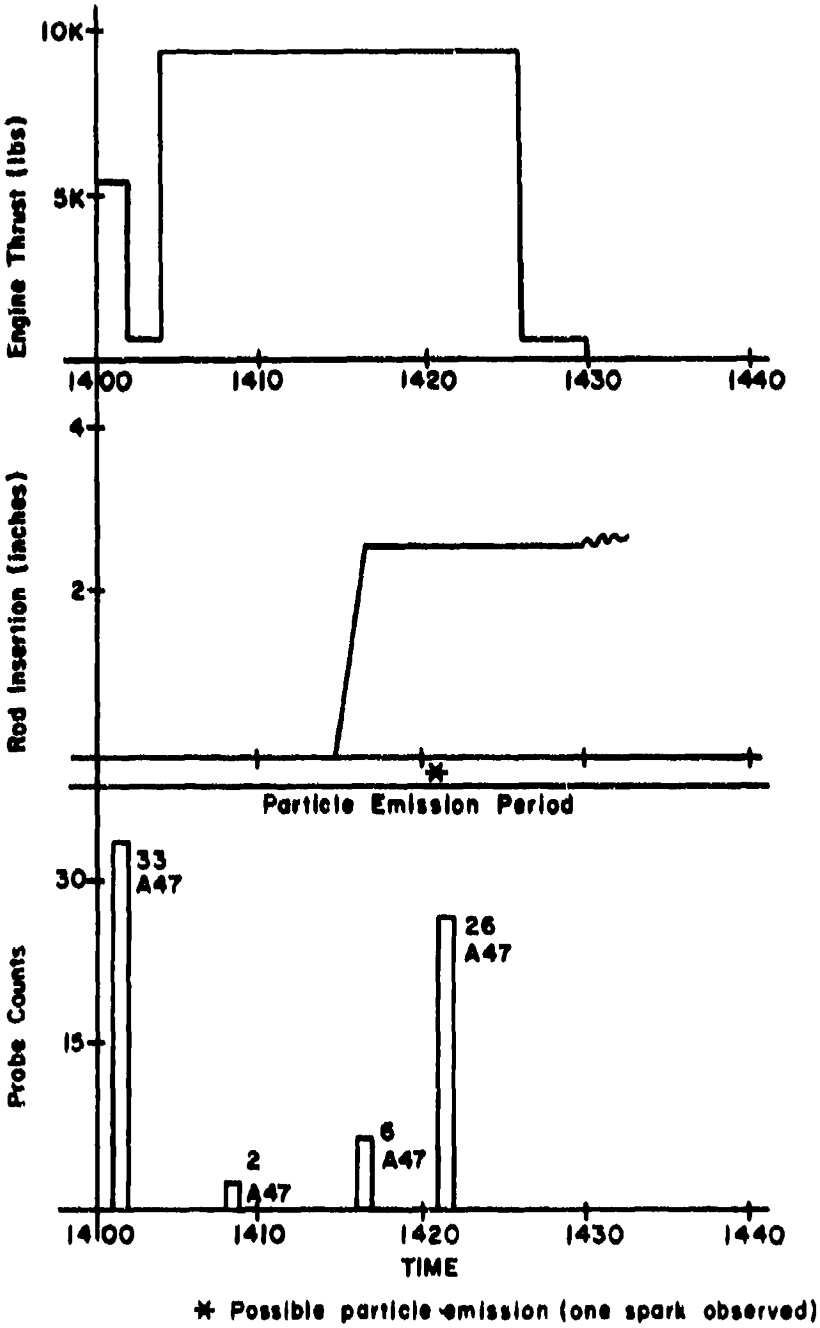


Figure 37. Time History, Test #6b

TABLE XII

ENGINE OPERATING CONDITIONS, TEST #7a (25 FEB 74)

Combustor Overtemp

Barometer: 29.41"Hg				TT2: 23°F			Normal Rated Thrust: 10500 Lbs
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1340	Start	-	-	-	-	-	Start. Idle.
1342	6000	-	-	-	-	-	Allow oil to heat.
1350	Idle	-	-	-	-	-	Go to idle.
1352	600	2300	6140	2.5	1000	440	Idle check.
1357	9800	-	-	-	-	-	Go to 9800 Lbs.
1400	9800	5320	8680	40.5	7500	965	Maintain 9800 Lbs.
1410	-	-	-	-	-	-	Start continuous burn rod insertion.
1413	-	-	-	-	-	-	Stop insertion. Depth 2.38". No sparks observed.
1415	Idle	-	-	-	-	-	Go to idle.
1418	600	2300	6100	3.0	1000	425	Rod not retracted.
1422	Stop	-	-	-	-	-	Shutdown.

COMMENTS: Rod in this case was stainless steel. No sign of material loss due to burn or melting, but some surface oxidation and contaminant coating. (See Figure 39).

The few counts recorded on probe systems are either background particle emission or electrical noise. No confirming signal documentation.

CONCLUSIONS: No significant distress. Few counts recorded before and during test period were due to background particles or electrical interference.

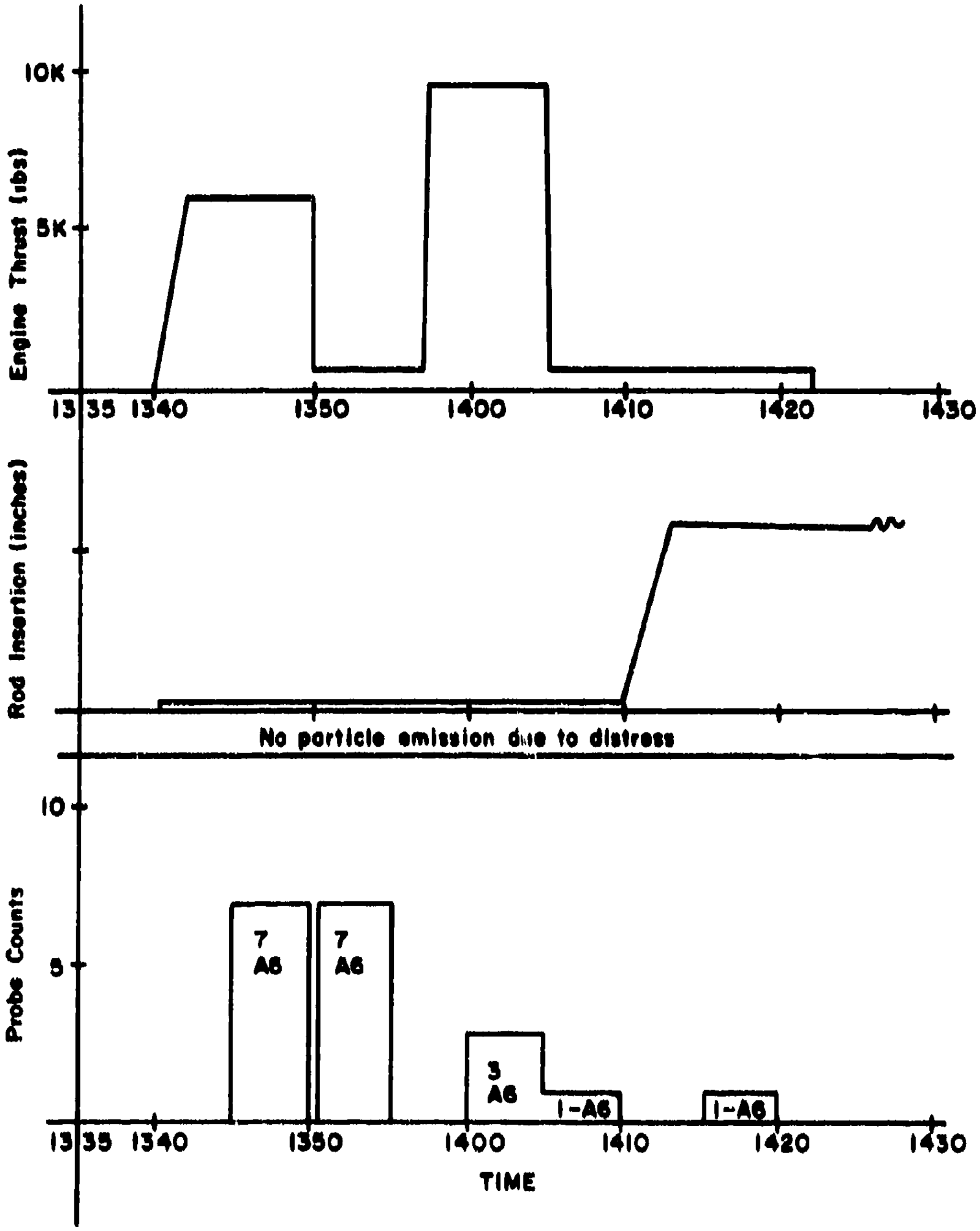


Figure 38. Time History, Test #7a

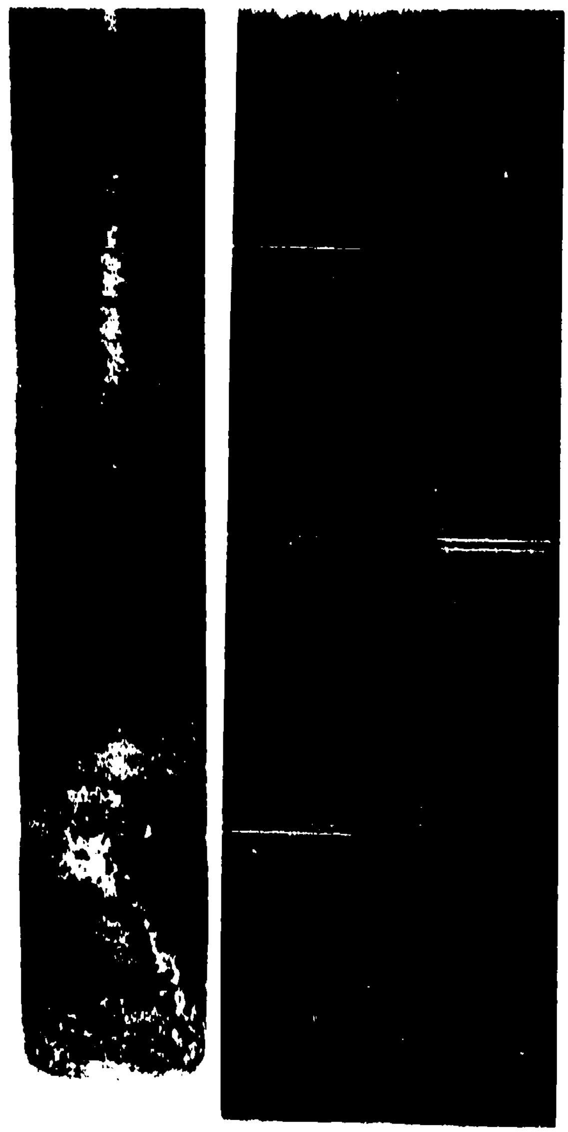


Figure 39. Burn Rod, Test #7a

TABLE XIII

ENGINE OPERATING CONDITIONS, TEST #7b (25 FEB 74)

Combustor Overtemp

Barometer: 29.42"Hg				TT2: 25°F		Normal Rated Thrust: 10500 Lbs	
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1507	Start	-	-	-	-	-	Start. Idle. Burn rod inserted 2.4".
1509	6500	-	-	-	-	-	Allow oil to heat.
1512	5400	4600	8020	20.5	4000	690	
1515	10000	-	-	-	-	-	Go to 10000 Lbs.
1518	10000	5400	8720	42.0	7700	975	Maintain thrust setting.
1530	Idle	-	-	-	-	-	Go to idle.
1533	Stop	-	-	-	-	-	Shutdown.

COMMENTS: About 2" of rod length (19.3 grams) was melted and/or burned away. Precise time at which rod began to loose material was not confirmed. Rod was left in throughout entire run. However, results of other tests (see test #8b, for example) at idle and at about 60%NRT indicate that rod deterioration would not be significant until the thrust was increased to above about 75%NRT. In this test burn could then be expected at 1515 thru 1530, although the precise time at which the immersed rod would be burned out was not known. As shown in Figure 40, most counts were recorded in the expected time period. The counts recorded just before and at the time of advancing to 10,000 lbs. are probably due to extraneous interference or background particle counts.

No waveform photos were obtained to document probe signals.

CONCLUSIONS: Most probe counts occured during the expected period of distress. However, no conclusive evidence of the actual time of distress or signal documentation was obtained.

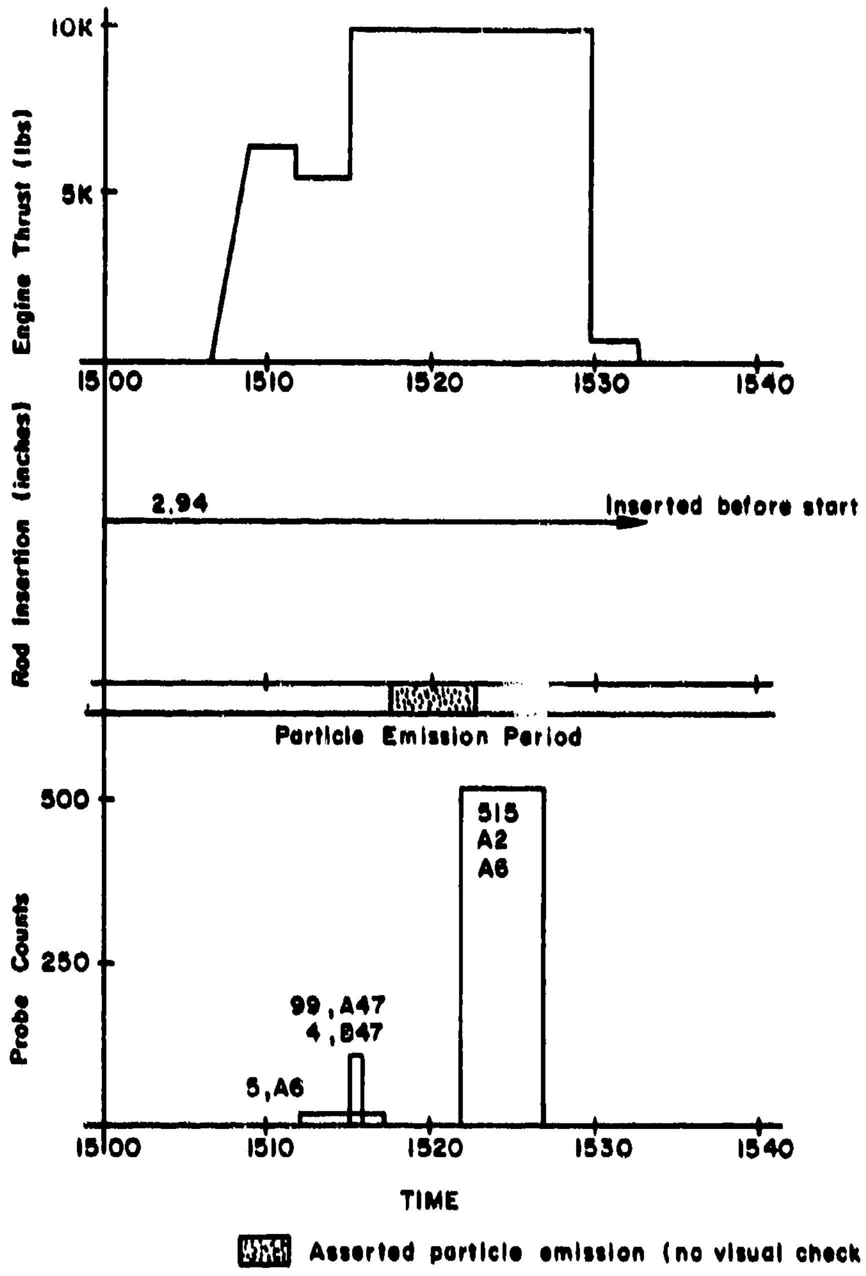


Figure 40. Time History, Test #7b

TABLE XIV

ENGINE OPERATING CONDITIONS, TEST #8a (26 FEB 74)

Combustor Overtemp

Barometer: 29.56"Hg			TT2: 30°F			Normal Rated Thrust: 10250 Lbs	
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1307	Start	-	-	-	-	-	Start. Idle.
1309	2500	-	-	-	-	-	Go to 2500 Lbs. Heat oil.
1310	5000	-	-	-	-	-	Go to 5000 Lbs. Heat oil.
1314	6000	-	-	-	-	-	Go to 6000 Lbs. Heat oil.
1318	Idle	-	-	-	-	-	Go to idle.
1320	9750	-	-	-	-	-	To to 95%NRT.
1323	9500	5340	8700	40.0	7600	970	Maintain thrust.
1328	-	-	-	-	-	-	Begin continuous burn rod insertion.
1331	-	-	-	-	-	-	Intermittent sparks observed.
1333	-	-	-	-	-	-	Insertion completed. Depth 2.94".
1335	-	-	-	-	-	-	Retract burn rod.
1337	-	-	-	-	-	-	Retraction completed. Depth .93".
1339	Idle	-	-	-	-	-	Go to idle.
1342	600	2240	6020	2.5	1000	440	Idle.
1344	Stop	-	-	-	-	-	Shutdown.

COMMENTS: A 1-7/16" length of rod melted and/or burned away in this successful simulation of localized combustor overtemp. Particle emission sparks observed intermittently during rod insertion. (Weight of missing material about 14 gm.)

No probe counts.

CONCLUSIONS: No probe detection of distress.
Zerc probe counts.

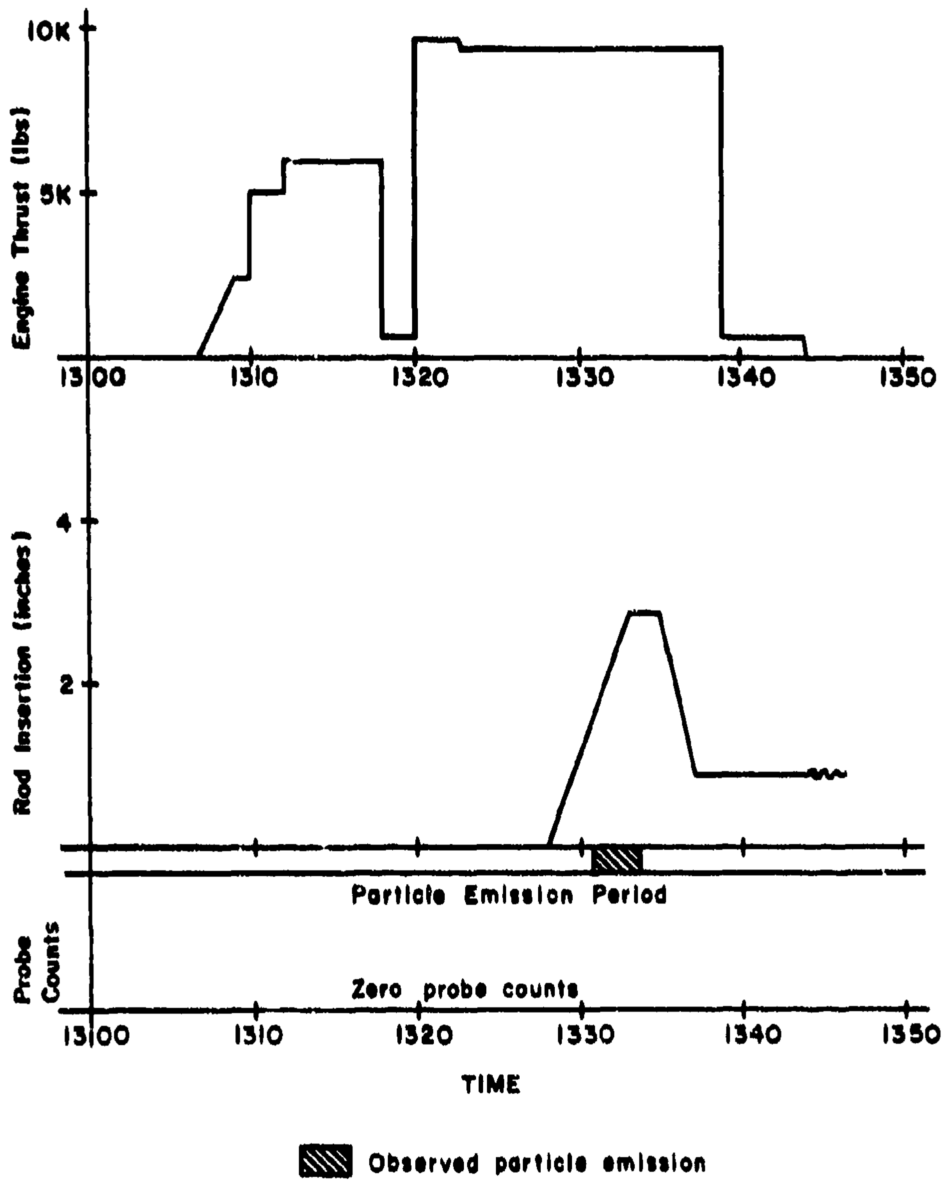


Figure 41. Time History, Test #8a

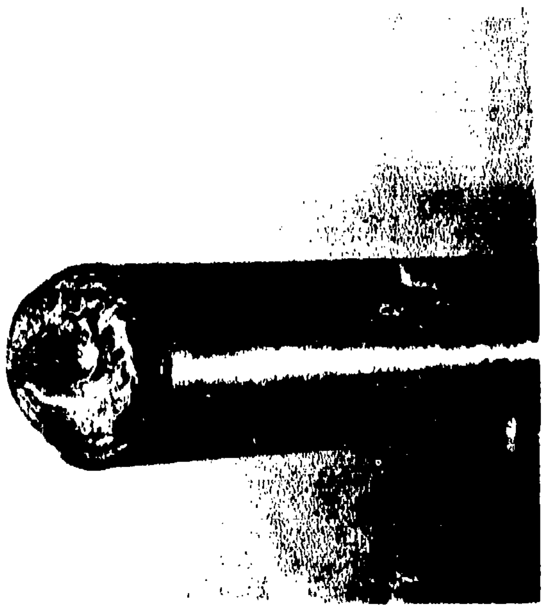


Figure 42. Burn Rod, Test #8a

TABLE XV

ENGINE OPERATING CONDITIONS, TEST #8b (26 FEB 74)

Combustor Overtemp

Barometer: 29.55"Hg TT2: 30°F Normal Rated Thrust: 10250 Lbs

TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
1358	Start	-	-	-	-	-	Start. Idle.
1400	6000	-	-	-	-	-	Allow oil to heat.
1402	Idle	-	-	-	-	-	Go to idle.
1404	600	2220	6040	2.5	900	440	Idle. Maintain idle.
1407	-	-	-	-	-	-	Begin continuous burn rod insertion.
1410	-	-	-	-	-	-	Stop insertion. Depth 2.94".
1413	-	-	-	-	-	-	No burn sparks observed.
1416	-	-	-	-	-	-	Start rod retraction.
1418	-	-	-	-	-	-	Stop rod retraction. Depth .93".
1419	7500	-	-	-	-	-	Go to 7500 to purge oil.
1420	Stop	-	-	-	-	-	Shutdown.

COMMENTS: Rod was inserted at about 60%NRT in an effort to determine if burn would take place at this setting, thus also serving to clarify results of test 7b. No significant material loss was observed in post-test inspection, but some pitting and oxidation was noted. (See Figure 44.) No particle emissions were observed, indicating also that detection would not be expected.

No probe counts.

CONCLUSIONS: Little, if any, significant distress. Zero probe counts.

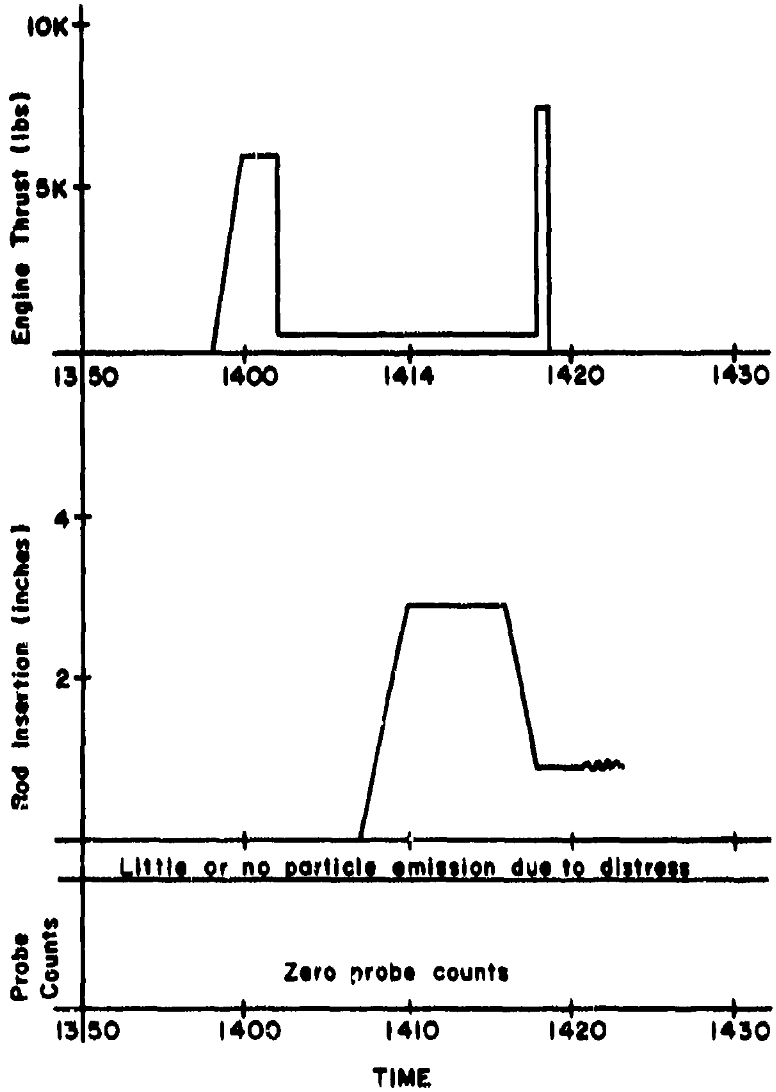


Figure 43. Time History, Test #8b

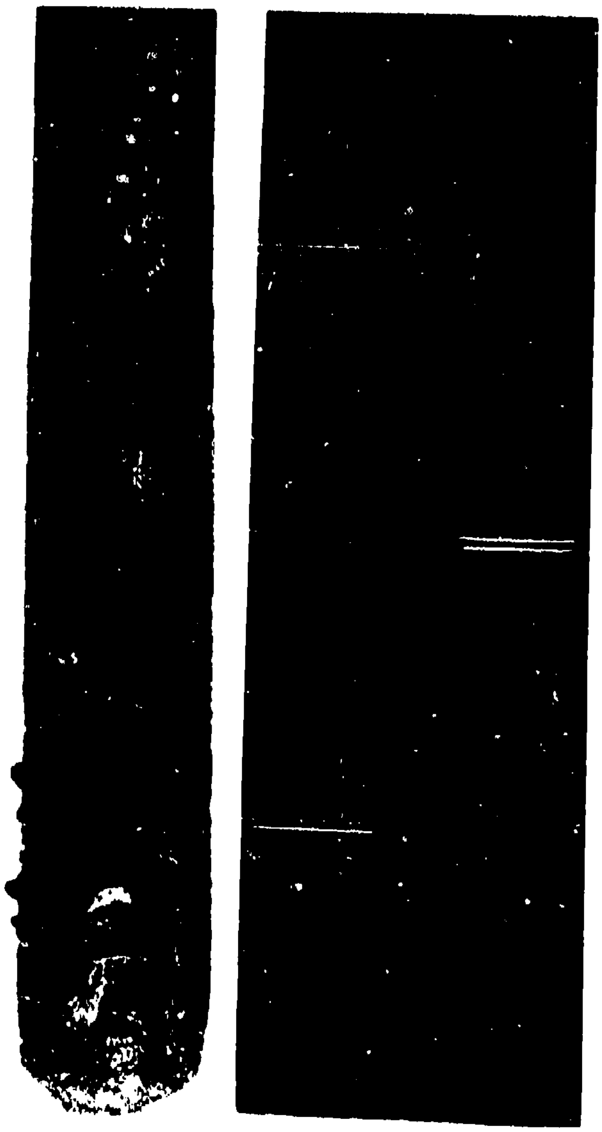


Figure 44. Burn Rod, Test #8b

TABLE XVI

ENGINE OPERATING CONDITIONS, TEST #9 (17 MAR 74)

LP2 Turbine Rub

Barometer: 29.19"Hg				TT2: 43°F		Normal Rated Thrust: 9500 Lbs	
TIME	THRUST (Lbs)	N1 (RPM)	N2 (RPM)	TURB DISCH PRESS ("Hg)	FUEL FLOW (Lb/Hr)	AVG TT7 (°F)	REMARKS
0921	Start	-	-	-	-	-	Start. Idle.
0926	4000	-	-	-	-	-	Allow oil to heat.
0931	3800	4300	7900	16.0	3300	640	
0946	7000	-	-	-	-	-	Accelerate to 7000 Lbs.
0949	7000	5020	8440	29.0	5600	860	
0954	9000	-	-	-	-	-	Accelerate to 9000 Lbs.
1000	9000	5400	8800	39.0	7400	990	Maintain 9000 Lbs.
1008	-	-	-	-	-	-	Start rub rod insertion.
1009	-	-	-	-	-	-	Total depth .08".
1011	-	-	-	-	-	-	Total depth .16".
1012	-	-	-	-	-	-	Sparks observed over 7 sec.
1013	-	-	-	-	-	-	Sparks observed over 25 sec Total depth .32".
1014	-	-	-	-	-	-	Sparks observed over 2 sec. Total depth .48".
1015	-	-	-	-	-	-	Sparks observed over 7 sec.
1016	-	-	-	-	-	-	Sparks observed over 2 sec. Total depth .64".
1018	9000	5400	8800	3900	7400	990	
1019	-	-	-	-	-	-	Retract rub rod.
1021	-	-	-	-	-	-	Rod retracted.
1022	Idle	-	-	-	-	-	Go to idle.
1025	Stop	-	-	-	-	-	Shutdown.

COMMENTS: For this test, electrostatic probes were electrically biased at a negative potential of about -67 volts in an effort to enhance static discharge signals as has been observed in other testing on J57 engines. Otherwise this test was comparable to tests 4b and 5. About 0.8 grams of material was rubbed away at 95%NRT. (Figure 46.)

Many counts recorded throughout the entire run, but all appeared to be noise similar to that due to bad probe cable connections. (See Figure 47.) The actual origin of these signals could not be resolved, although at least one cable was determined to have a faulty line, thus accounting for a very high count rate.

CONCLUSIONS: Severe electrical interference. Unable to establish a satisfactory correlation between counts and distress.

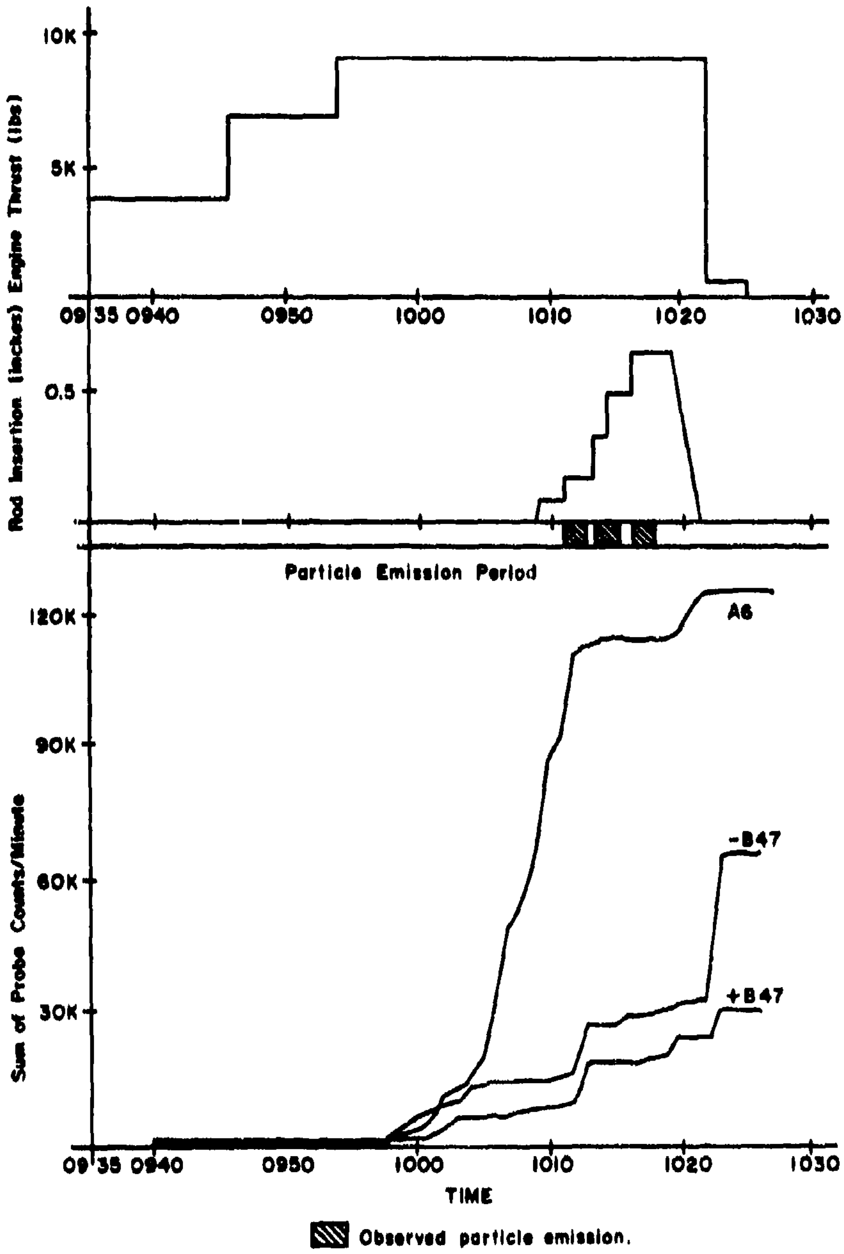


Figure 45. Time History, Test #9

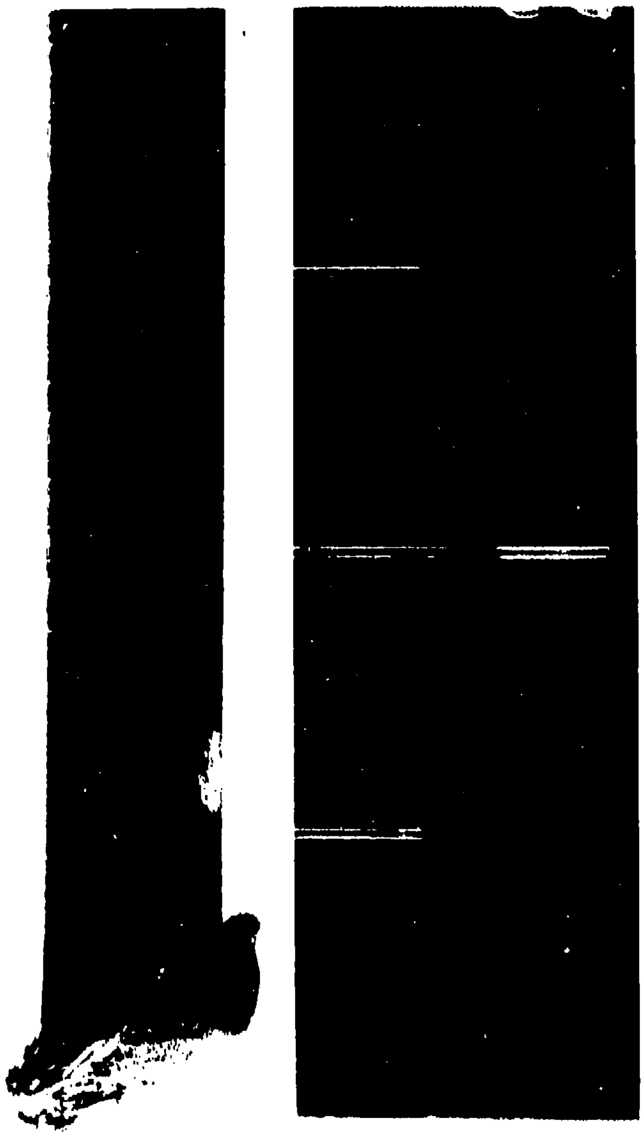
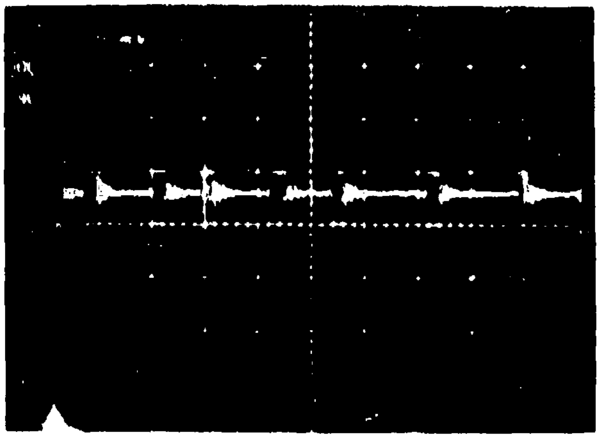


Figure 46. Rub Rod, Test #9



Test: 9
Date/Time: 15 Mar 74, 0955
Engine: J57-37
Cable: Not recorded
Probe: Not recorded
V/Div: 50mV, AC coupled
T/Div: 1 microsecond

Figure 47. Noise Pulse, Test #9

Remarks: This pulse is representative of signals observed during this test. The irregular pulse shape is the same as that observed when there is a loose probe cable connection shaking due to engine vibration; however, the liklihood of all cables having the same problem simultaneously is remote. Also, the number of pulses generally increased with thrust, as may be seen in Figure 45. As all probes were biased to -67 volts (by a circuit specially built for this test), the biasing arrangement itself may have caused the system to be excessively sensitive to extraneous signals.

SECTION IV
ANALYSIS

Since the probe technique is under evaluation as a turbine engine diagnostic tool and must therefore give reliable data information permitting straightforward interpretation, the requirements for consistency and freedom from false indications become imperative. Therefore, it is the opinion of the authors that the preliminary results of Table II be interpreted with that forethought.

The analysis below proceeds stepwise, with each step involving the inclusion of more discriminating evidence. Following each step, significant test events are separated into favorable, unfavorable, and indifferent categories. "Significant test events" are defined as (1) instances of probe counts and/or (2) instances of distress. The critical insight into the nature of the problem is gained when these events are correlated.

As a first step in analyzing the data, the results of Table II were classified strictly on the basis of when the counts occurred versus the time period when the distress occurred. The result of this step is displayed in Table XVII. The categories are explained below.

TABLE XVII
TIME CORRELATION OF TEST EVENTS
(* indicates test where distress occurred at idle.)

	Distress	No Distress
Counts	3a*, 3b, 5 7b, 9	2, 3a, 5, 6b 7a, 7b, 9
No Counts	1*, 2*, 3b* 4a, 4a* 4b, 8a	6a, 8b

The tests listed in Table XVII as having both counts and distress (upper left quadrant) imply favorable probe indications. The instances of counts with no distress (upper right quadrant) imply false probe indications and are highly unfavorable. Instances of distress with no probe counts (lower left quadrant) imply that for some reason the probe did not detect the distress and are more or less indifferent results, although they do imply inconsistency. The two cases of no distress and no counts are of little significance and exist only because the simulation attempts were completely unsuccessful in these cases. That is, there were no significant test events for Tests 6a and 7a. Therefore, for those tests where significant events did occur, Table XVII says generally that results were approximately equally divided among favorable, unfavorable, and indifferent categories. However, no strong conclusions can be drawn without consideration of the types of probe signals obtained and their implication in regard to the authenticity of the probe counts.

The mixed results of Table XVII can be clarified by including in this analysis an assessment of the nature of the signals producing the counts. This assessment was made only for the cases where counts were recorded as the most significant events. Namely, those cases of satisfactory probe indications and cases of false indications.

Among the 12 events with counts, Test #2, 6b, 7a, and 7b has no signal waveform documentation. For these cases, no conclusive remarks can be made concerning the origin of the signals producing the counts. However, each of these tests are in the false alarm category, and it can safely be assumed that the counts were due to background particles or electrical interference. Signal waveform photos for Test #3a (Figures 22, and 23) indicate counts due to electrical interference, based on the premise that charged particle detection implies net charge transfer to the probe. Thus, the counts in both the distress and no-distress categories must actually be considereed false indications. Test 3b, which is shown in Table XVII as a satisfactory probe indication, must be reconsidered also in view of Figures 26 and 27. Three counts of probe signals were recorded at the time that rub was not believed to have occurred. The associated waveform clearly indicated net charge transfer to the probe, allowing one to conclude that the signal was possibly due to charged particle detection. On the other hand, the nine counts at time 1430 have the appearance of interference and do not serve as an indication of particle detection.

Table XVII lists Test #5 as producing counts which correlate in time with distress and some counts interpreted as false indications. The associated waveform photos were not taken at the time the counts were recorded but if one assumes the same type signals produced the recorded counts, then one may conclude that the counts are possibly due to particle detection. However, due to the lack of time correlation, this assessment cannot be made except by implication.

As with Test #5, Test #9 also produced counts that were in correlation with distress and those that were not. Signal waveforms (Figure 47) indicate that the profuse number of counts were due to interference associated with the biasing of the probes and possibly loose connections.

The net results of the above discussion are listed below in Table XVIII. The reader will note that consideration of the probe signal waveforms has further reduced the number of favorable probe indications beyond that suggested in the preliminary results of Table II.

Table XVIII indicates that it is necessary to readjust the listing in Table XVII to reflect not only the time correlation of counts with distresses, but also to reflect the judgment as to signal authenticity. This was accomplished by comparing Table XVII to Table XVIII. The result is given below in the final results of Table XIX. Note that the three tests categorized as favorable probe indications of distress are actually only possible indications, since the evidence was incomplete or inconclusive for these cases.

TABLE XVIII

CORRELATION OF PROBE COUNTS

Test#	Confirmed counts in correlation with distress	Counts in possible correl. with distress	False counts or background counts	False counts due to elect. interference
1	0	0	0	0
2	0	0	10,000	0
3a	0	0	0	3114
3b	0	3	0	9
4a	0	0	0	0
4b	0	0	0	0
5	0	361	104	0
6a	-	-	-	-
6b	0	0	67	0
7a	0	0	19	0
7b	0	515	108	0
8a	0	0	0	0
8b	-	-	-	-
9	0	0	0	200,000

TABLE XIX

FINAL CORRELATION OF TEST EVENTS

	Distress	No Distress
Counts	3b, 5 7b	2, 3a, 3a* 3b, 5, 6b 7a, 7b, 9
No Counts	1*, 2*, 3b* 4a, 4a* 4b, 8a	6a, 8b

*Distress occured at idle.

As the above results strongly suggest that there may be no true positive correlation of distress and counts, the question arises as to whether the remaining three tests in the upper left quadrant above could be explained purely in terms of chance counts during the distress time period. This possibly is reinforced by the observation that the periods of distress with particle emission constitute about 10% of the total test time (neglecting the special case of Test #9), while about the same percentage of counts occurred during the same period. (Refer to the time history tables in the individual test results.)

In summary, the analysis shows that the more critical the examination of the probe data, the more apparent it becomes that a genuine correlation cannot be established between probe counts and particles emitted during engine distress.

SECTION V
CONCLUSIONS

(1) No confirmed cases of probe counts due to detection of charged particles were recorded for distresses simulated in this evaluation.

(2) Except for the chance correlation of some probe counts with distress, the vast majority of test events must be classified as cases of false probe indications or cases where the probe failed to indicate particle emission due to distress.

(3) If one assumes that signals due to charged particles were present (however small), then one must conclude that they could not be reliably detected above the background noise level.

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